PL-TR-96-2269

INTERACTIVE WORLD WIDE WEB PAGES FOR CUSTOM EVENT SCREENING AT THE PROTOTYPE INTERNATIONAL DATA CENTER

Mark D. Fisk
Richard J. Carlson
Valeriu Burlacu
Gary D. McCartor

Mission Research Corporation
8560 Cinderbed Road, Suite 700
Newington, VA 22122

30 September 1996

Scientific Report No. 2

Approved for public release; distribution unlimited

PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AFB, MA 01731-3010

19970311 086

DTIC QUALITY INSPECTED 3

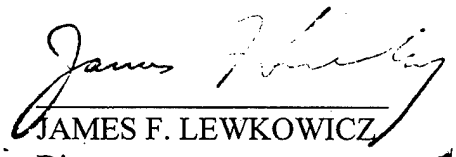
SPONSORED BY
Advanced Research Projects Agency (DoD)
Nuclear Monitoring Research Office
ARPA ORDER No. 0325

MONITORED BY
Phillips Laboratory
CONTRACT No. F19628-93-C-0101

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either express or implied, of the Air Force or U.S. Government.

This technical report has been reviewed and is approved for publication.

DELAINE R. REITER
Contract Manager
Earth Sciences Division



JAMES F. LEWKOWICZ
Director
Earth Sciences Division

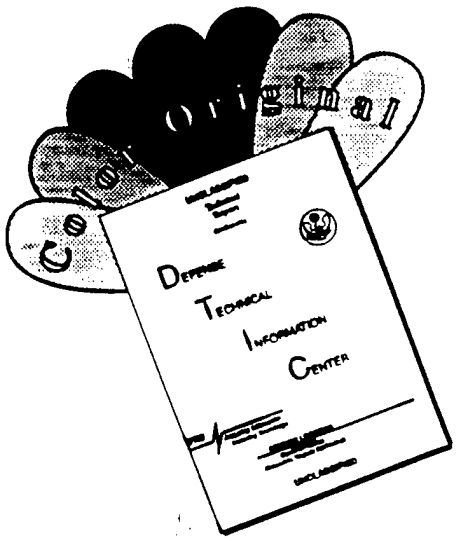
This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify PL/IM, 29 Randolph Road, Hanscom AFB, MA 01731-3010. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704.0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	30 SEP 1996	Scientific Report No. 2

4. TITLE AND SUBTITLE
Interactive World Wide Web Pages for Custom Event Screening at the Prototype International Data Center

5. FUNDING NUMBERS
Contract F19628-95-C-0101
PE 62301E
PR NM95 TA GM WU AA

6. AUTHOR(s)
Mark D. Fisk, Richard J. Carlson, Valeriu Burlacu,
Gary D. McCartor*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Mission Research Corporation
8560 Cinderbed Road, Suite 700
Newington, VA 22122

8. PERFORMING ORGANIZATION REPORT NUMBER
MRC/WDC-R-385

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
29 Randolph Road
Hanscom Air Force Base, MA 01731-3010
Contract Manager: Delaine Reiter/GPE

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-96-2269

11. SUPPLEMENTARY NOTES
* Department of Physics, Southern Methodist University, Dallas, TX

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public distribution;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes statistical event characterization tools and related data products being implemented at the Prototype International Data Center (PIDC) in Arlington, Virginia. Preliminary event screening analyses at the PIDC currently utilize seismic measures of location, depth, mb-Ms, and their uncertainties, as well as regional high-frequency amplitude ratios. To make these tools and data products accessible to remote users, interactive World Wide Web pages have been implemented for custom event screening. These Web pages provide a preliminary capability for users to select and analyze events based on event characterization parameters and user-defined screening criteria. A wide range of maps and other displays of the data and screening results are provided. These tools allow the user to process, view and download customized event characterization data products and graphics over the Internet. Two basic services are described: (1) an interactive event screening service which allows custom criteria to be provided and applied during an on-line session; and (2) a subscription service utilizing user-specified event screening criteria that remain in affect until they are changed by the user. Examples of how to access and use the Web pages, as well as applications to GSETT-3 data, are presented for the two types of services. A preliminary assessment of the event characterization capability at the PIDC, over time, is also presented. Results are described of an application to seismic events in Eurasia that occurred between 1 June and 31 July 1996. These events include two underground nuclear explosions at the Lop Nor test site in China and provide a useful test of the event screening tools.

14. SUBJECT TERMS
Custom Event Screening
Subscription Service
World Wide Web
International Data Center
Comprehensive Test Ban
GSETT-3

15. NUMBER OF PAGES
46

16. PRICE CODE

17. Security CLASSIFICATION OF REPORT	18. Security CLASSIFICATION OF THIS PAGE	19. Security CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

CLASSIFIED BY:

DECLASSIFY ON:

Table of Contents

List of Figures

List of Tables

1. Introduction

This effort focuses on development and integration of a software system for statistical event characterization and event screening at the Prototype International Data Center (PIDC) in Arlington, Virginia, and on quantifying seismic event characterization capabilities with regard to monitoring the Comprehensive Test Ban Treaty (CTBT).

Preliminary event screening analyses, currently installed at the PIDC, include utilization of confidence intervals for depth and mb-Ms to screen out events that are consistent with natural seismicity. Location error ellipses are also used to assess whether events occurred onshore or offshore, or in a given region, at a specified confidence level. (Offshore events will eventually be analyzed further using hydroacoustic data.) Due to current limitations in estimating depth and Ms for events below mb ~4.5, further analysis is based on regional seismic parameters which currently include high-frequency (e.g., 2-8 Hz) Pn/Lg and Pn/Sn. Due to regional variations and the lack of calibration data for nuclear explosions in most regions, we have developed a robust multivariate outlier test (or regional population analysis), based on the likelihood ratio, to compare events relative to the previous regional seismic activity[1]. The procedure assumes that: (1) there is at least one regional parameter that discriminates earthquakes and explosions; and (2) the number of new nuclear tests in a region will be small compared to other seismic activity. Fisk et al. (1993, 1994, 1995, 1996) describe the methodology in detail, as well as numerous applications to seismic data.

To make the event characterization tools and related data products useful and accessible to remote users, we have been implementing interactive World Wide Web pages for custom event screening (Fisk, 1996). Two basic services are currently being developed: (1) an interactive event screening service which allows custom criteria to be provided and applied during an on-line session; and (2) a subscription service utilizing default or user-specified event screening criteria that remain in affect until they are changed by the user. These Web pages provide a preliminary capability for users to perform selection and screening of events based on event characterization parameters and user-defined screening criteria. A wide range of maps and other displays of the data and screening results are provided. These tools allow the user to process, view and download customized event characterization data products and associated graphics over the Internet.

The current implementation of the Event Screening Web pages has focused on analysis of seismic events, since seismic processing capabilities at the PIDC are more mature than for the other

1. For applications to regions for which there are also training data for nuclear explosions, we have developed a classification test (Baek et al., 1996; Fisk et al., 1993), although this algorithm is not currently installed at the PIDC.

emerging monitoring technologies. However, event characterization parameters and screening capabilities, based on hydroacoustic, infrasound, radionuclide and fusion techniques, are being implemented at the PIDC, and will be reflected in future versions of the PIDC Web pages.

In this report, we describe the event characterization services and data products currently available at the PIDC Web site. In Section 2, we describe the interactive event screening tools and present results of applications to GSETT-3 data collected from the existing Primary seismic stations. In Section 3, we describe a standard set of event characterization data products, computed on a daily basis, as well as a subscription service to allow users to customize the criteria used to generate these products. In Section 4, we present a preliminary assessment of the event characterization processing capability over time at the PIDC. In Section 5, we present results of an application to events in Eurasia that occurred between 1 June and 31 July 1996. These events include two underground nuclear explosions at the Lop Nor test site in China and provide a useful test of the event screening analyses. Last, in Section 6, we provide some conclusions and recommendations.

2. Interactive Web Pages for Custom Event Screening

The interactive Web pages currently allow the user to select (1) a region of interest; (2) a time period of interest; (3) a seismic magnitude range; and (4) criteria and confidence levels for defining an event as deep, with mb-Ms below a user-specified threshold, and whether the event was onshore or offshore. In addition, the user can select regional event characterization parameters and other criteria with which to compare regional events to the historical event population in their respective regions. The screening tools are applied to events in the *Reviewed Event Bulletin (REB)*, i.e., to events after human analyst review. The criteria allow the user to define which events are of interest and to screen out the remainder. A wide range of maps and other displays of the data and event screening results are provided. The visualization tools are interactive, with hyperlinks, allowing the user to select event markers or data points in various displays to obtain additional information.

Users who wish to access the PIDC Event Screening Web pages must have some form of workstation, Macintosh or personal computer with a connection to the Internet, with, preferably, a 14.4 kilobit per second data transfer rate or faster. In addition, a Web browser, such as Netscape, is required. To utilize the full functionality of the existing PIDC Web pages, Netscape 3.0 or a more recent release is recommended. (We also plan to provide a non-graphical capability for event screening in the future, to support users who cannot satisfy these requirements.) Using Netscape, for example, the Custom Event Screening Web page may be accessed by entering the WWW URL: *http://www.cdidc.org:65120/mseas_bin/Custom_EventChar.*

These Web pages are in the development stage and, as such, documentation and on-line help are currently limited, but will be provided in greater detail in the future. Further questions regarding access and use of these Web pages may be directed to Mark Fisk by e-mail at fisk@cdidc.org.

To illustrate the functionality of the interactive Web pages, we now provide an example of how a user might apply these tools to analyze a set of events recorded during a given period of time. The map in Figure 1 shows the locations of 1859 events that were recorded by the Primary seismic network between 15 July 1996 and 16 August 1996, and were reviewed by seismic analysts at the PIDC. Of the 1859 events, 1434 were mb 3.5 or larger. The map has several projection and zoom functions to focus on a region or events of particular interest. Detailed information regarding a particular event or station can be obtained by clicking on the event or station marker, which have hyperlinks to the *REB* or Network Information Web pages, respectively.

Associated with the map is a form (Figure 2) which allows the user to select a region, time period and magnitude range of interest. Once these parameters have been set as desired, the user clicks on the "Retrieve Data" button, which accesses the data from an Oracle database at the PIDC. In this example, only events of mb 3.5 or larger are considered in the subsequent analyses. This form also allows the user to specify criteria and confidence levels for defining an event as deep, with mb-Ms less than a cut-off, and/or whether the event was offshore, accounting for uncertainties. Further screening analyses for offshore events, using hydroacoustic data, will be provided once relevant data are available. (See GSE/CRP/243, 1995, for descriptions of how relevant parameters are computed. Bottone et al., 1996, describe how confidence intervals for mb-Ms are computed.) Users may save their custom criteria and simply load the saved form into their browser to perform similar runs during future sessions. Screening criteria may be set differently in various regions if desired.

The preliminary screening analyses are executed by clicking on the "Submit Run" button. This returns a Web page (Figure 3) displaying a map of the events, color-coded by whether they were *Screened* (green), *Not Screened* (red), had *Insufficient Data* (blue), or were *Not Considered* (gray). In this example, events below mb 3.5 are placed in the *Not Considered* category. Events are placed in the *Screened* category if the entire 90% confidence interval for focal depth is deeper than 10 km, the entire 90% confidence interval for mb-Ms is less than 1.2, or the 90% location error ellipse is entirely offshore. Events lacking data to perform any of these tests are placed in the *Insufficient Data* category. The remaining events are placed in the *Not Screened* category. Of the 1434 events considered in this case, 778 were screened out, 249 have data but were not screened based on any of the criteria, and 407 did not have adequate data to perform any of these three tests. The regional population analysis will be performed shortly to further screen the remaining events.

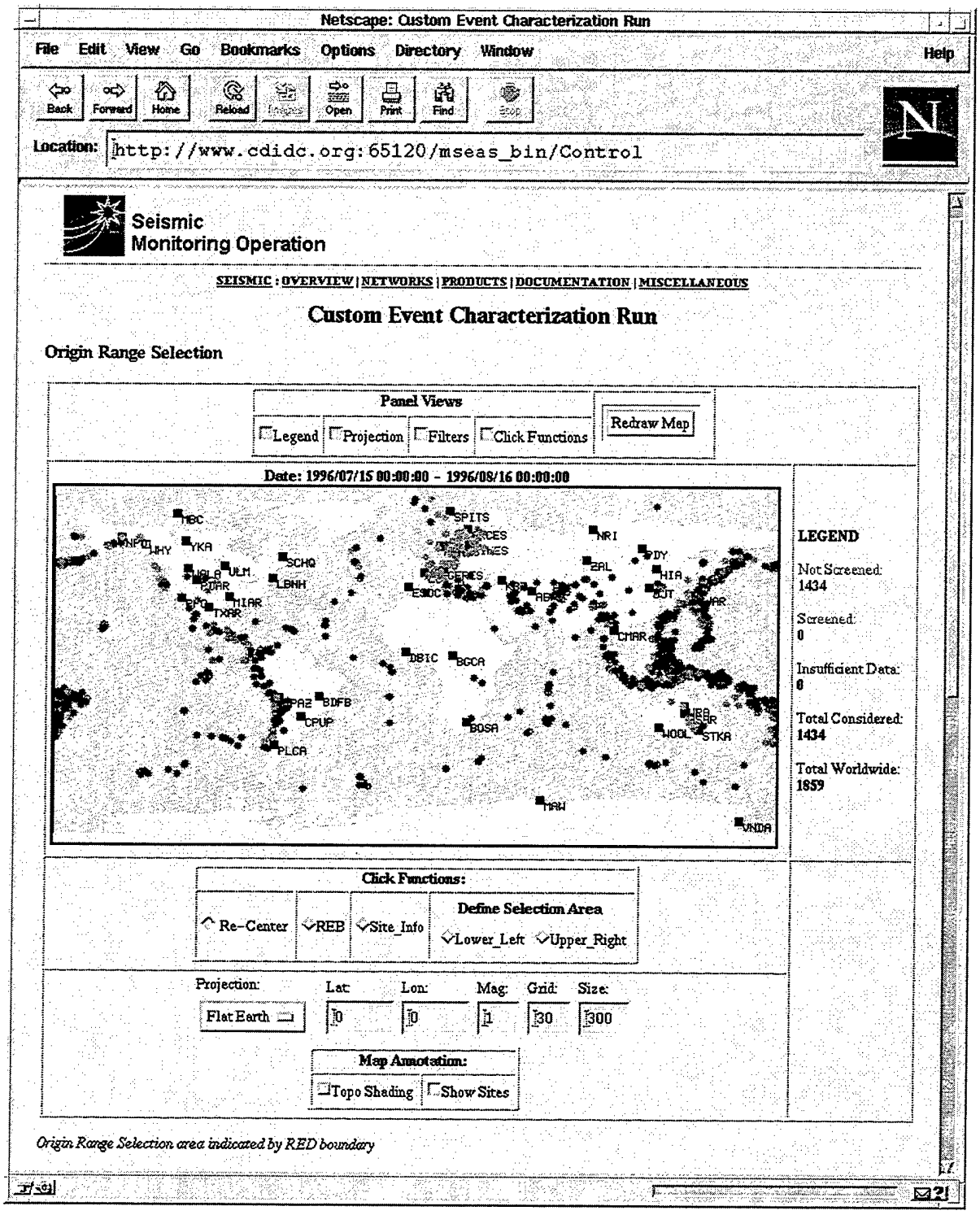


Figure 1. **Interactive World Wide Web page for custom event screening. The map shows locations of the existing Primary seismic stations and seismic events to be analyzed. The map has numerous projection and zoom functions. The station and event markers have hyperlinks to site information and seismic bulletins, respectively.**

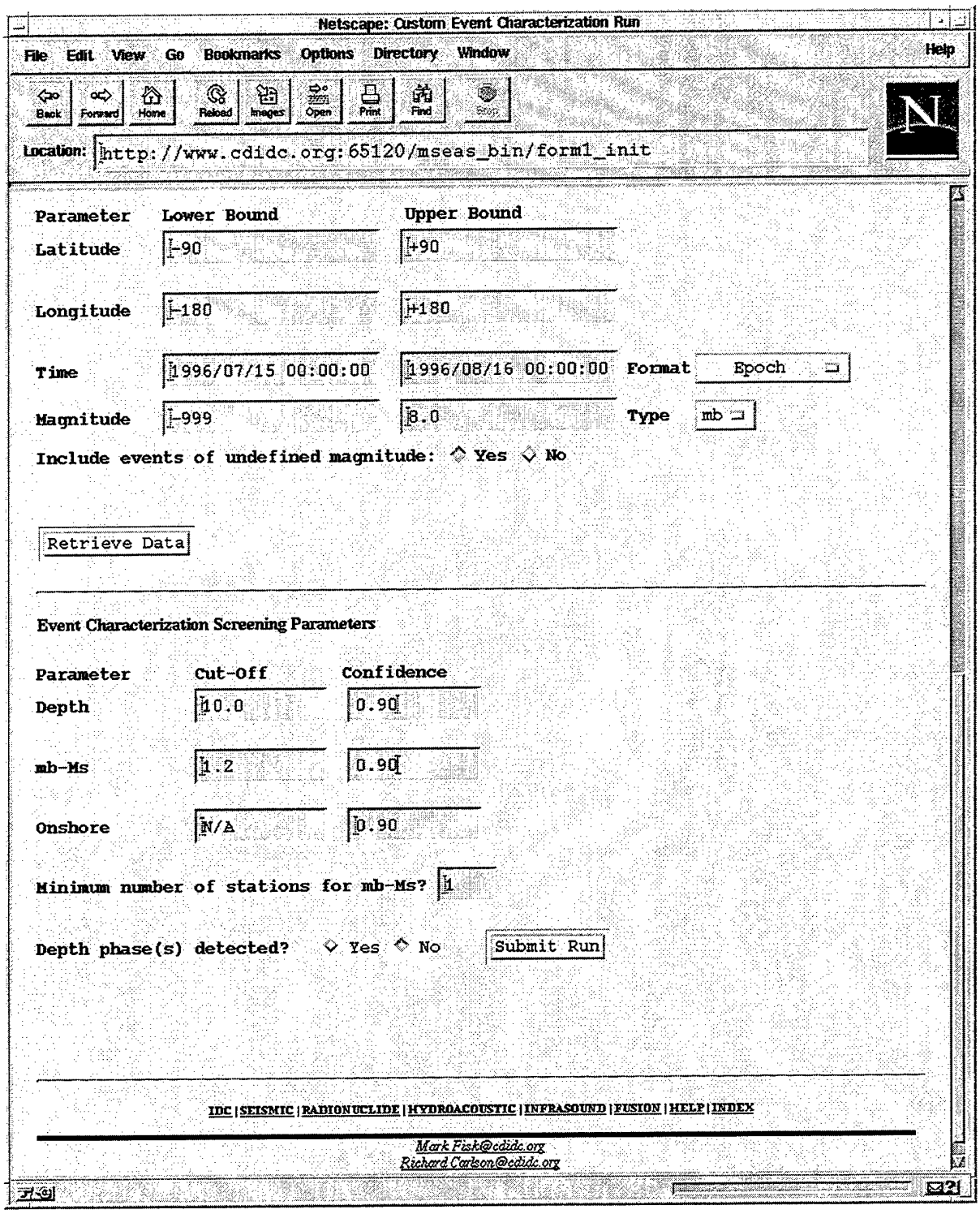


Figure 2. Form to select a region, time period and magnitude range, as well as to specify criteria and confidence levels for defining an event as deep, with mb-Ms below a given threshold and/or whether the location error ellipse was onshore or offshore.

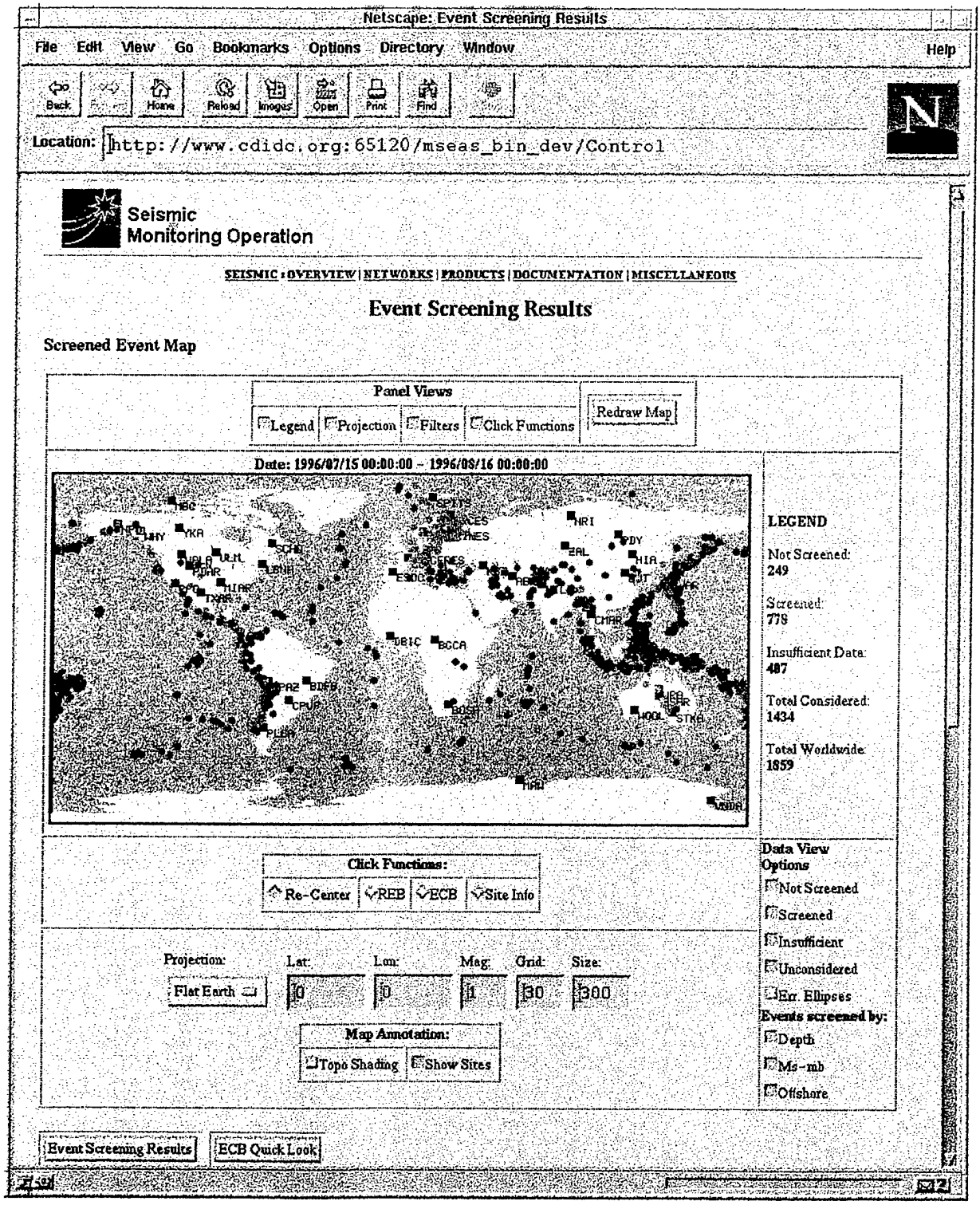


Figure 3. **Map display of preliminary screening results. Event markers are color-coded based on the results. Effects of the various individual and combined screening criteria can be examined using the "Data View Options" buttons to the lower right of the map. Options are also available to display the event location error ellipses and to modify the map size, projection, origin and magnification.**

The user may examine the effect of the various individual and combined screening criteria by selecting or de-selecting the "Data View Options" buttons to the lower right of the map. An option is also available to display the event location error ellipses. The event characterization data and the screening results may be viewed by selecting the "Event Screening Results" button at the bottom of this page. This produces numerous displays of the results (Figure 4). Data markers on these plots may be selected with a mouse to obtain further information, e.g., to link to the *REB* Web page.

By clicking on a thumbnail-size plot on the left of Figure 4, an enlarged plot is displayed, as shown on the right, for example, of the upper bound of the 90% confidence interval for depth versus the upper bound of the 90% confidence interval for mb-Ms. Each marker is color-coded by whether the event was screened (green) or not screened (red). Events depicted by the red markers in the upper right rectangle of the plot were not screened by either criteria. (Note that the markers with mb-Ms > 3.5 actually correspond to events without Ms measurements. That is, for the sake of making this plot, Ms is set to zero for events with no Ms measurement.)

The rectangular region on the lower lefthand side of this plot corresponds to depth and mb-Ms values with, possibly, conflicting evidence, since deep events are not expected to have large Ms measurements relative to mb. In this example, the event in this category has a 90% depth confidence interval deeper than 100 km and a 90% mb-Ms confidence interval less than 1.2. By either test, the event is screened; however, such events are flagged so that an analyst can review the data to verify that the depth and magnitude estimates were computed properly.

Figure 5 shows a plot of Pn/Lg values in the 4-6 Hz band at each Primary seismic station for the events during this period. The markers are coded by whether the signal-to-noise ratio (SNR) is greater than or less than two, as defined in the legend. Similar plots are available for Pn/Sn and for other frequency bands. This plot shows that some stations have limited or no regional Pn/Lg values for this time period, and that many of the values have SNR values less than two.

Using the regional event characterization data, the events can now be compared to historical events in their respective regions, employing a multivariate population (or outlier) analysis (e.g., Fisk et al., 1993, 1994, 1995, 1996). Using the form in Figure 6, the user can select which regional event characterization parameters to use, a signal-to-noise criteria, a magnitude cut-off, a minimum training set size and the statistical significance at which an event is rejected as a member of the remaining regional population. Additional regional event characterization parameters will be added to this form once codes to compute them are installed at the PIDC. After the parameters have been set, the analysis is executed by clicking on the "Submit Run" button.

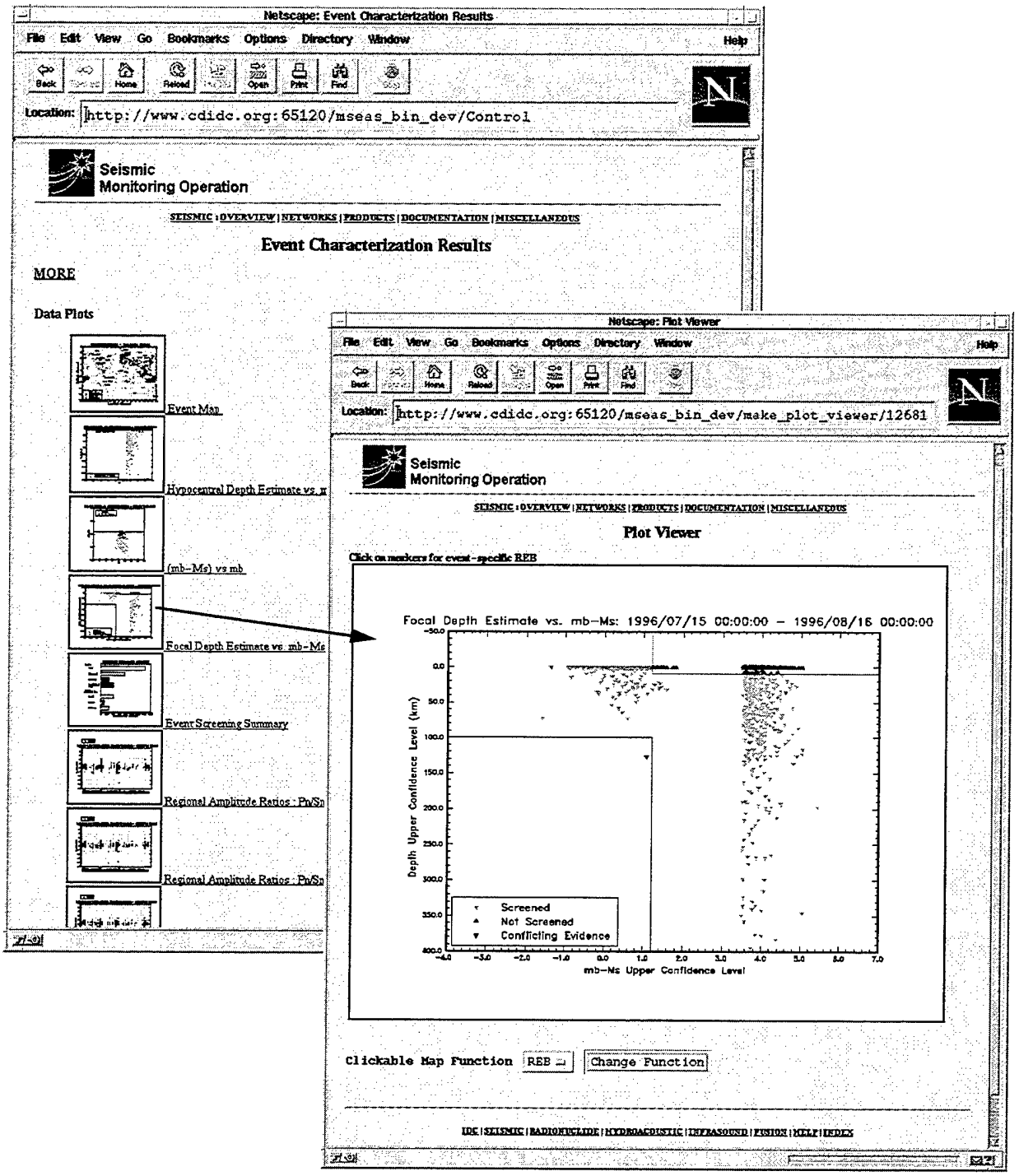


Figure 4. **Web page to display the various event characterization parameters and screening results. The thumbnail-size graphics on the left are enlarged by clicking on them. The example on the right shows an enlarged plot of the upper bound of the 90% confidence interval for depth versus the upper bound of the 90% confidence interval for mb-Ms. Markers in the upper right rectangle of the plot correspond to events that were not screened by either depth or mb-Ms. Note that the markers with mb-Ms > 3.5 correspond to events without Ms measurements.**

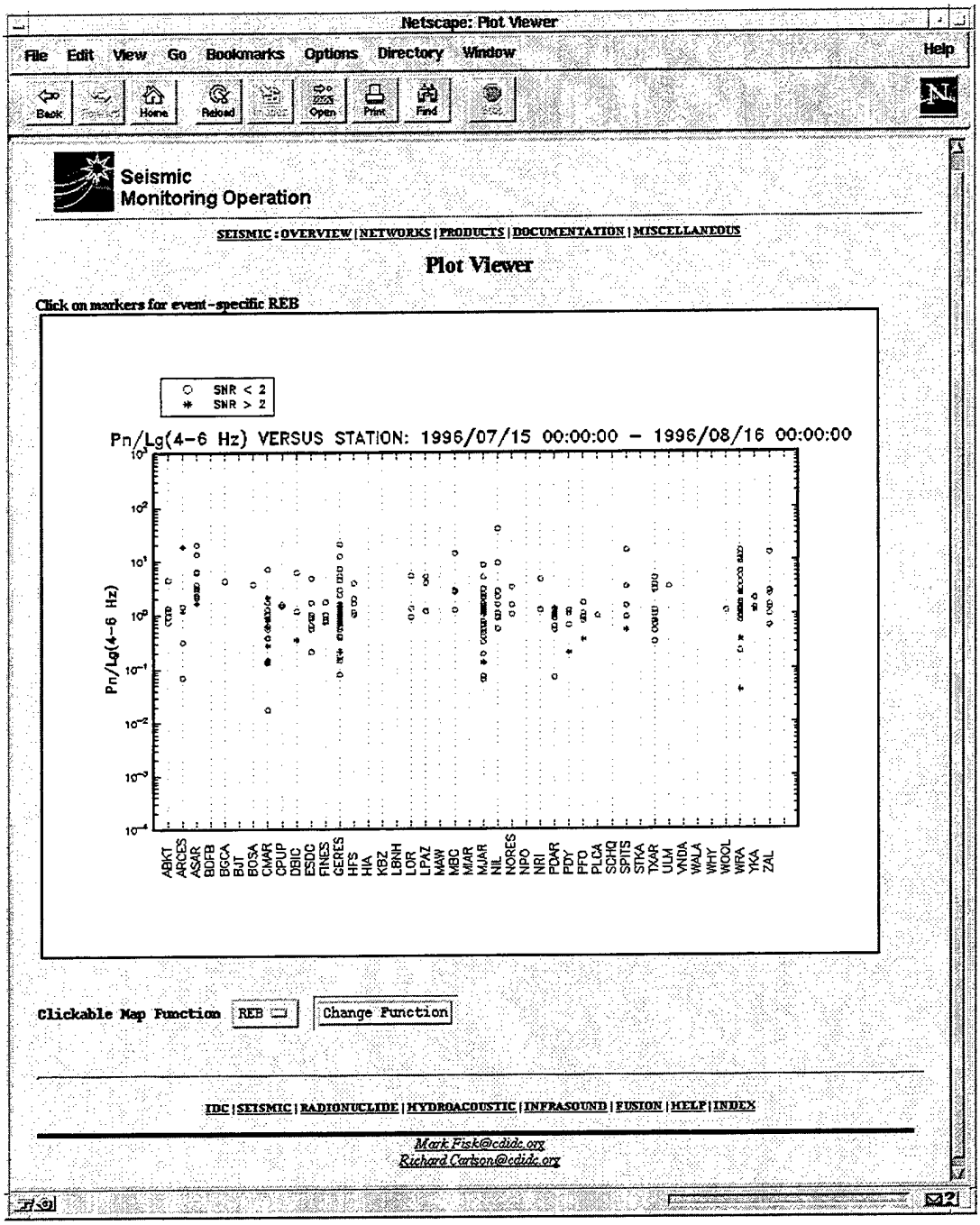


Figure 5. Pn/Lg values in the 4-6 Hz band at each Primary station for the events during this period.

Once the population analysis is complete, a Web page appears (Figure 7), similar in appearance, color-coding and functionality to that shown in Figure 3. This page displays a map of the screening results, including the results of the depth, mb-Ms, offshore/onshore and regional population analyses. From this page, plots of the event characterization parameters and the previous screening results, as well as plots of the population analysis results, can be accessed.

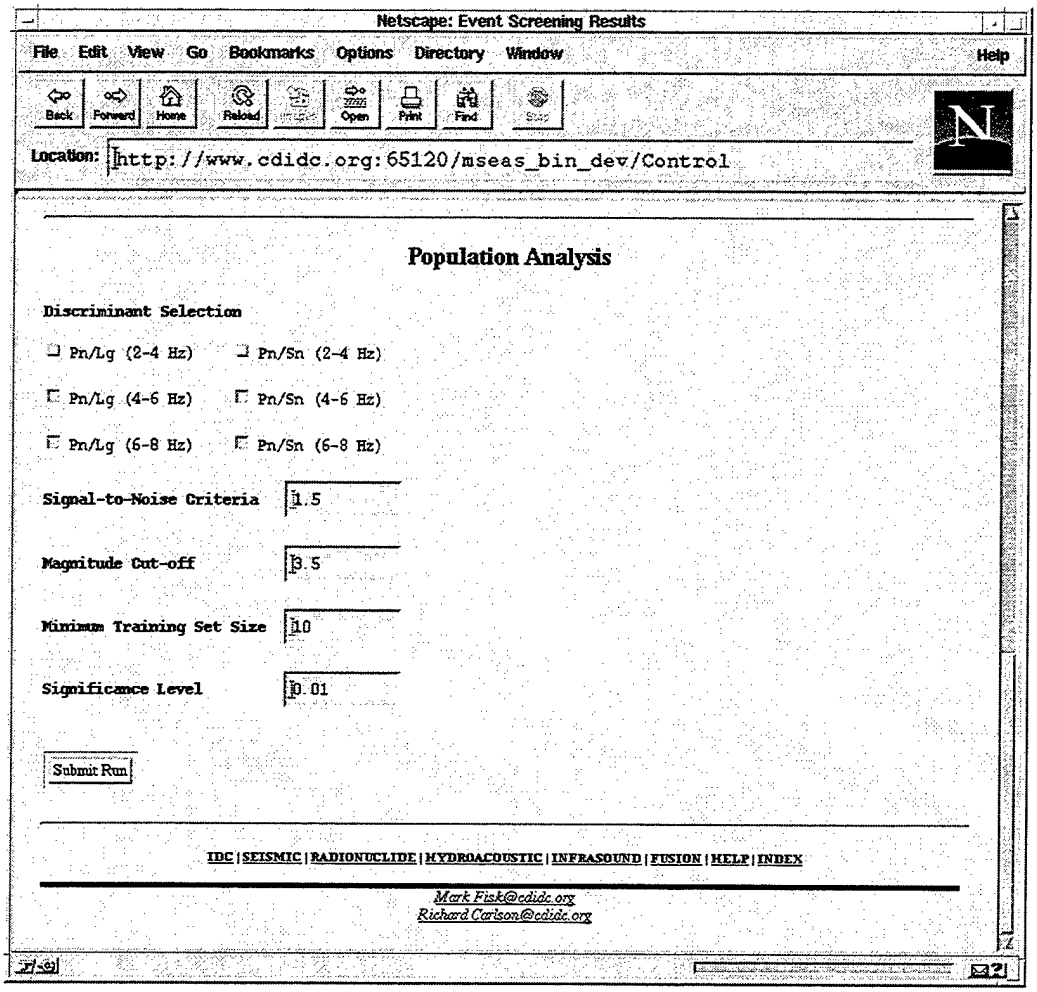


Figure 6. Form to select regional event characterization parameters and other criteria for the regional population analysis.

Figure 8 shows an example of plots depicting the results of the regional population analyses for the individual stations. Note that there were only 17 of the GSETT-3 stations with regional training sets at the time this analysis was performed. As before, a plot is enlarged by clicking on the thumbnail-size version. These plots show how new events compare to historical events, as well as to a threshold defined by the user's inputs. Markers to the left of the vertical line correspond to events that are rejected as being a member of the same population in the particular region, at the specified significance level, in this case, 0.01. Shown here is an enlarged plot of the population analysis results for Auxiliary station NIL in Pakistan. The circles correspond to the historical events, while the triangles correspond to the new events being tested. In this case all but one of the new events were found to be consistent with the regional event population. The event which was found to be inconsistent with the previous seismicity in this region was an underground nuclear test conducted at the Lop Nor test site in China on 29 July 1996. As for the other types of plots, the user can click on a marker to obtain the *REB* Web page for the event and other information.

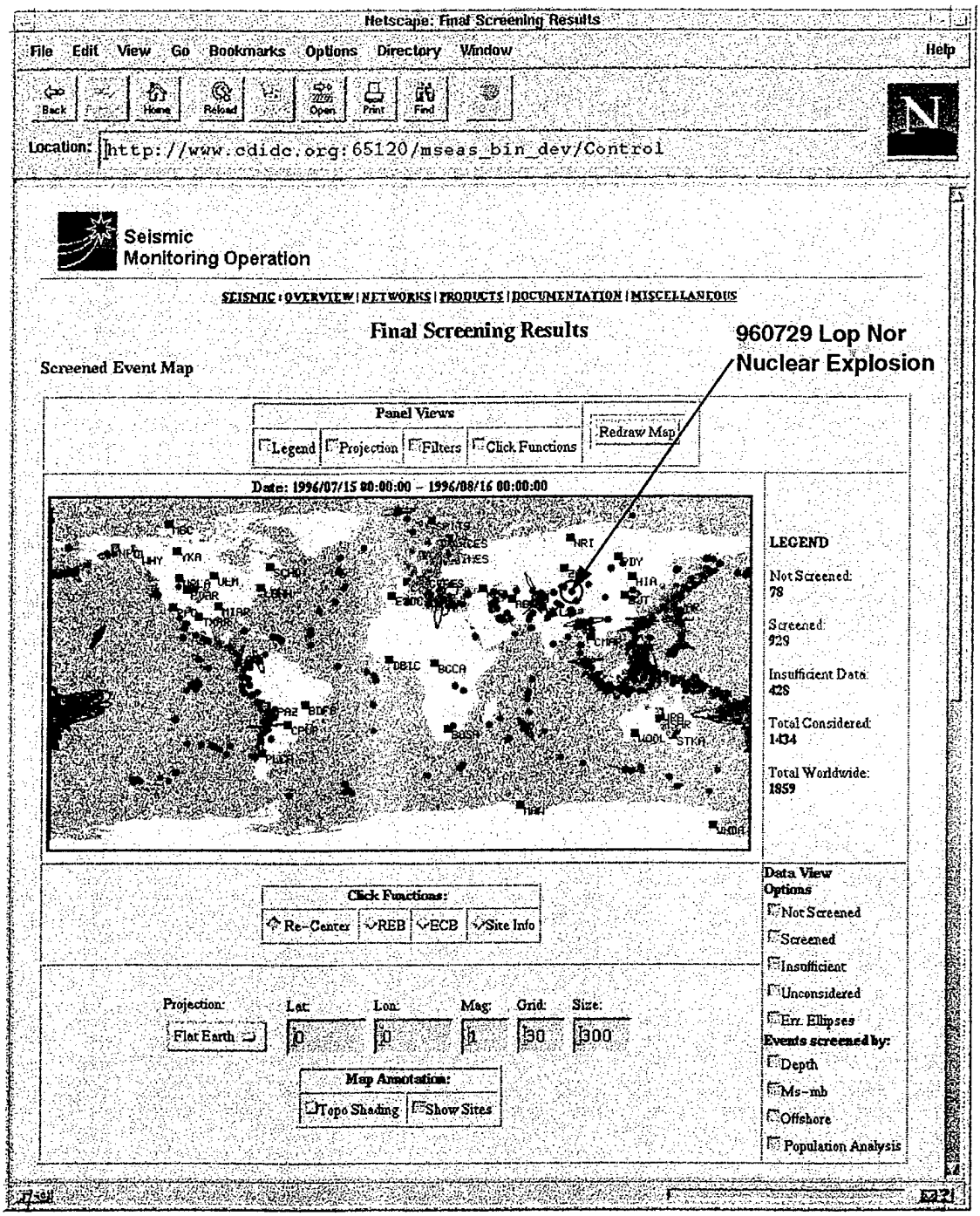


Figure 7. Map showing seismic events, with location error ellipses, and color-coded by their screening results.

The map in Figure 1 shows the events before any screening has been applied. The map and legend in Figure 7 illustrate the combined effect of applying the screening criteria. Of the 1859 events which occurred between 15 July and 16 August 1996, 1434 were mb 3.5 or larger, of which 428 currently have insufficient data to perform the screening tests, 928 were screened out and 78 were not screened out, based on the screening criteria in this example.

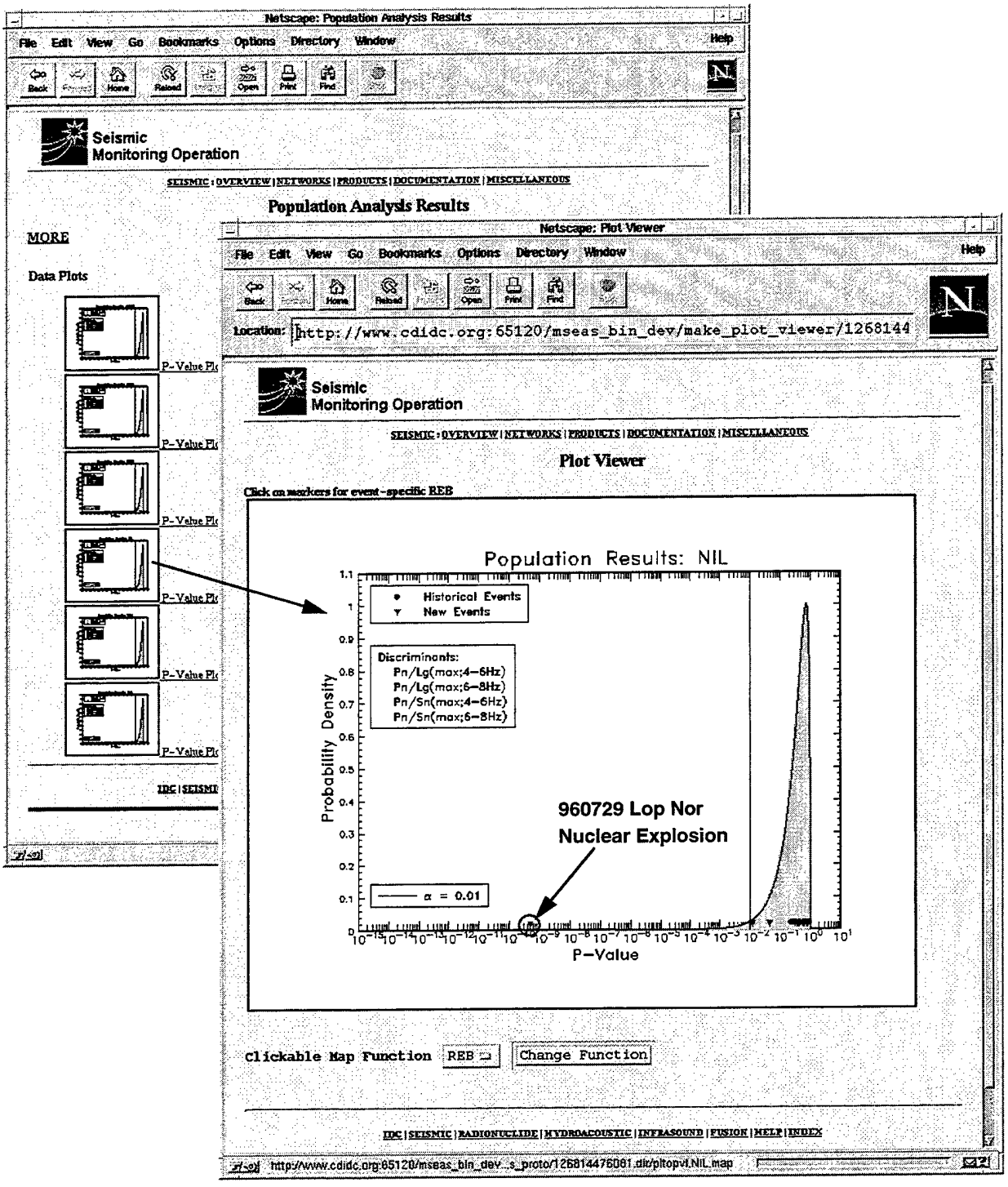


Figure 8. **Displays of regional population analysis results. On the right is an enlarged plot of the results for station NIL. In this case, the 960729 Lop Nor nuclear test was the only event flagged as an outlier.**

Table 1 summarizes the numbers and percentages of events (relative to the number of *considered* events) that were screened by the various criteria. Approximately 28% were screened by depth, 11% by mb-Ms, 32% by offshore location, and 15% by the regional population analysis. Note that many events were screened by multiple criteria. Of the *considered* events, 30% had *insufficient data* with which to perform the screening tests, 65% were *screened out*, and 5% were *not screened.*

Table 1. Summary of the events screened by various combinations of tests.

Screening Category	Number	Percentage
Depth	400	28%
mb-Ms	160	11%
Offshore	464	32%
Regional Population Analysis	220	15%
Depth and/or mb-Ms	513	36%
Depth, mb-Ms and/or Offshore	778	54%
Depth, mb-Ms, Offshore and/or Population Analysis	928	65%

These results show how the interactive event screening tools can be used to reduce the number of seismic events during a given period to a more manageable number for further investigation. Note that the International Monitoring System (IMS) Network is still incomplete and event characterization processing capabilities are evolving rapidly at the PIDC. Currently we have regional training sets for only 17 seismic stations, roughly 10% of the total set of Primary and Auxiliary seismic stations in the proposed IMS Network. As the full set of Primary and Auxiliary seismic stations come on-line, and as more regional data are computed over time, we will continue our on-going efforts to establish regional training sets. (We plan to describe this work in detail in a subsequent report.) We expect that this will eventually reduce the number of events with insufficient event characterization data to a much smaller percentage of the overall events.

Codes to compute additional event characterization parameters are also being integrated into the processing pipeline at the PIDC (Jepsen and Fisk, 1996), which should further aid in screening a higher percentage of the events in the future. New parameters include waveform complexity, spectral variance, 2-D cepstral features, a short-period to long-period energy ratio, autoregressive analysis of Lg waves, and others. The efficacy of these parameters needs to be investigated for various regions. Parameters that reliably distinguish mining blasts from other types of events are needed to permit useful event screening analyses for events below mb 3.5.

3. Event Characterization Products and Subscription Service

In addition to the interactive event screening tools, we have been developing automated event characterization products which include *Executive Summaries*, *Event Lists*, *Bulletins,* and displays of the *Signal Parameters* and *Raw Data*. The automated analyses are executed each day after the events are reviewed by expert analysts. The *Executive Summaries* provides top-level information regarding the total number of events detected and those in various screening categories. System status is also summarized to reflect the IMS Network and IDC processing capabilities for the appropriate time period. The *Event Lists* summarize the events detected in various regions and by the particular monitoring technique(s). From the *Event List*, there are links to the *Reviewed Event Bulletin (REB)* and the *Event Characterization Bulletin (ECB)*, the latter of which we have recently developed. The bulletins provide in-depth information regarding the events and associated signal measurements from the raw signals. The *ECB* provides hyperlinks to displays of relevant event characterization parameters and will eventually have links to the raw data.

In conjunction with these Web pages, we have also been implementing an automated subscription service, to allow PIDC users to establish regions of interest and custom event screening criteria, which may vary for different regions. This subscription service is currently being coordinated with David Salzberg of the Center for Monitoring Research (CMR), who is developing a unified service for all subscriptions and on-demand requests via e-mail, ftp and the World Wide Web. In this section, we first describe the standard (or default) data products, and then describe how the user can customize these products to support their specific monitoring objectives.

3.1. Standard Data Products

The Web pages containing these data products may be accessed by first going to the PIDC home page (*www.cdidc.org*), shown in Figure 9, and then clicking on the "Data Products" button to go to the *Data Products* page, shown in Figure 10. The page shown in Figure 10 has menus to select any of the data products currently available through the PIDC Web site. Once a particular product, e.g., *Executive Summaries*, has been selected from the menus, the user clicks on the "Done" button, which produces a Web-page dialog to select a date of interest (Figure 11).

Figure 12, for example, shows the *Executive Summary* for 8 June 1996, which provides high-level information regarding the *total* number of events detected, those which were *considered* in the screening analysis (i.e., those above mb 3.5), those which were *not screened out*, and those with *insufficient data* to perform the screening tests. Currently event screening is performed using only seismic data, as described in Section 2. Future work will incorporate hydroacoustic, infrasonic and radionuclide screening procedures to form a fused summary.

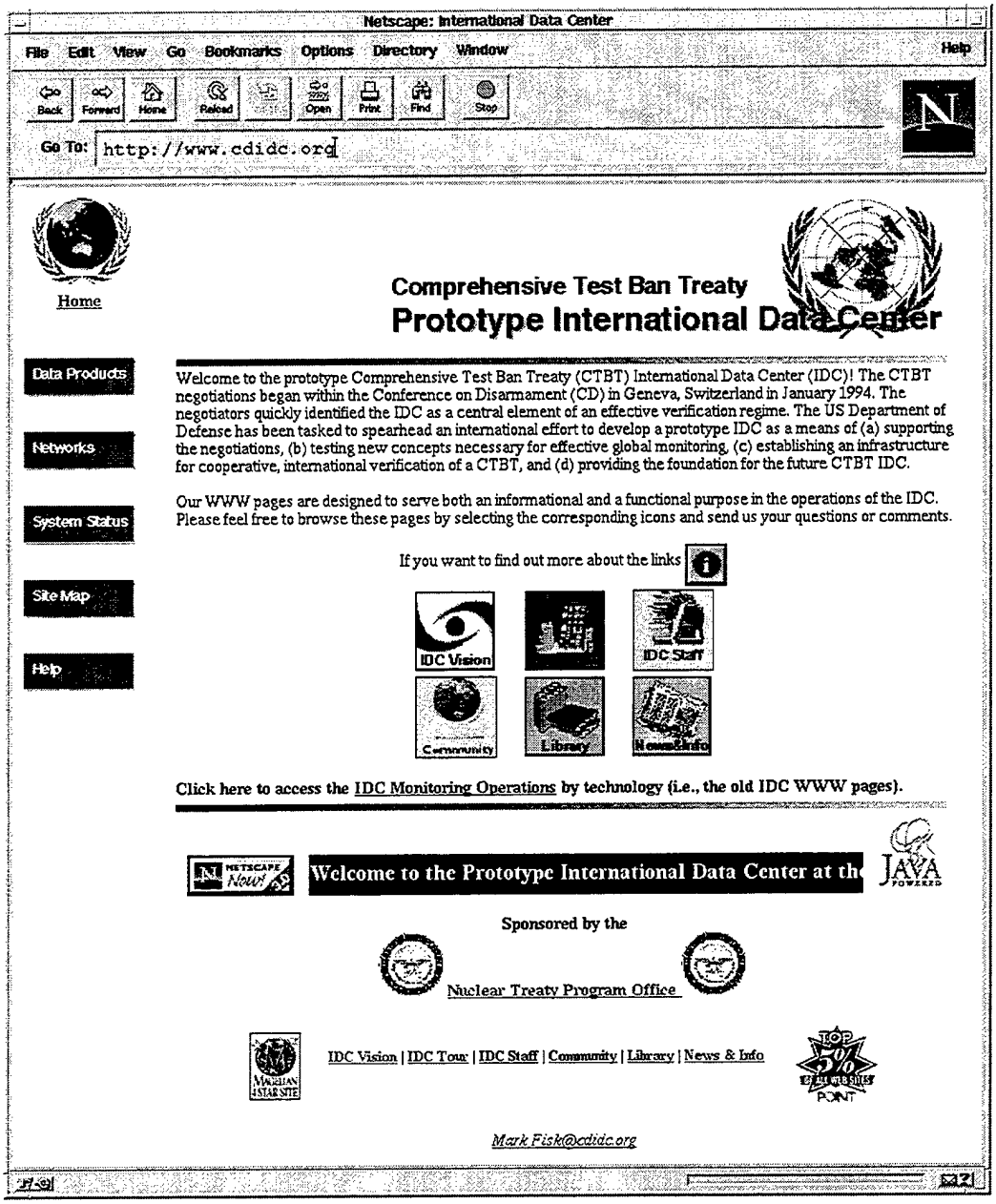


Figure 9. World Wide Web home page for the Prototype International Data Center.

Detection of Level 4 radionuclide events (e.g., ones for which fission products were detected) will be summarized separately on this page (Figure 12). Due to the time delay in collecting and processing radionuclide data relative to data for the other monitoring technologies, two boxes are provided to indicate those Level 4 events detected during the time period in question, as well as those correlated with events previously located by the other monitoring techniques, possibly over a two week period. In addition, system status is summarized on this page to reflect the IMS Network and IDC Processing capabilities for the time period in question. Some of these entries are still in the development stage as indicated by "TBD."

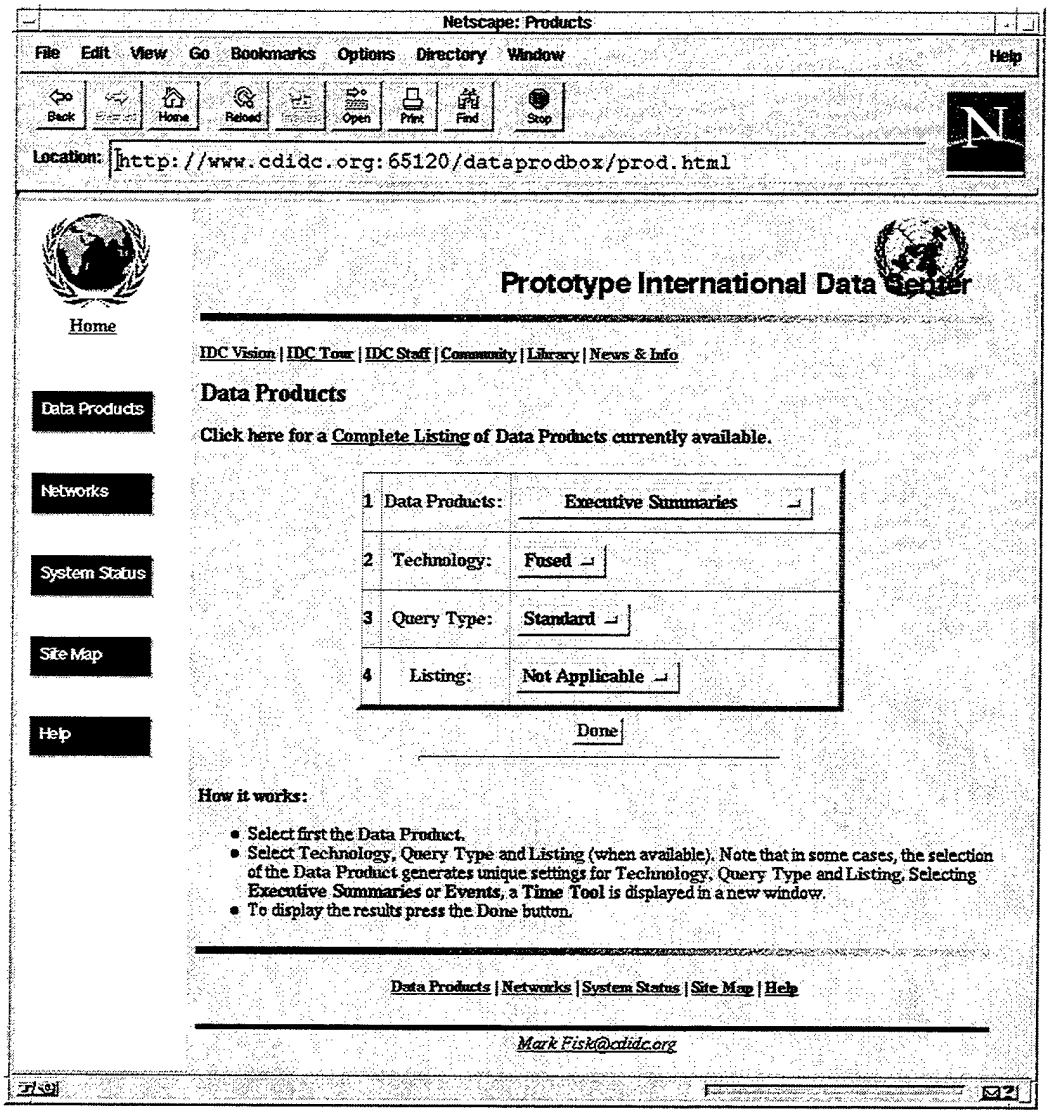


Figure 10. Web page to access the data products at the PIDC.

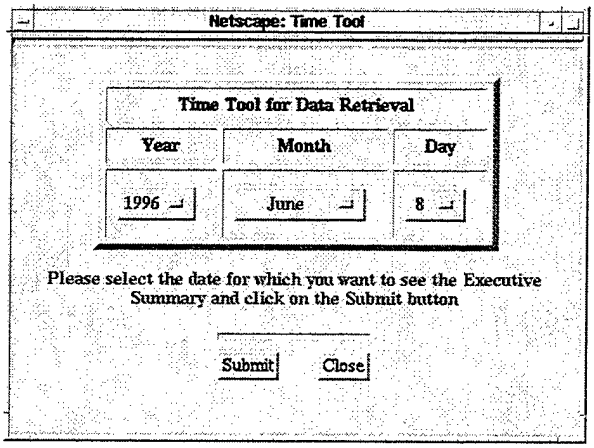


Figure 11. Dialog to select a date for the *Executive Summaries and Event Lists*.

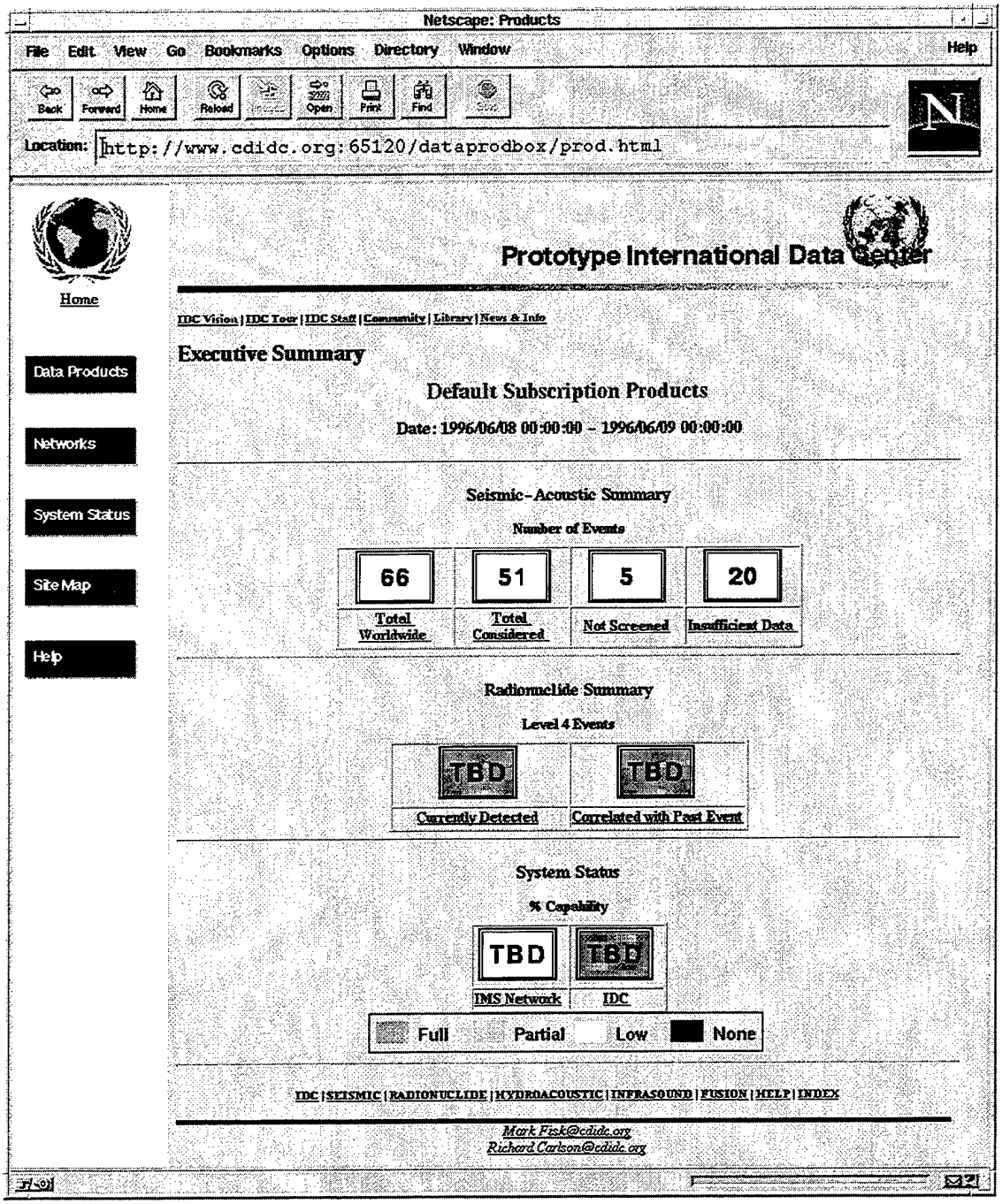


Figure 12. Example of the *Executive Summary* Web page for 8 June 1996.

The boxes depicted in Figure 12 may be selected with a mouse click to obtain more detailed information and graphical displays. For example, Figure 13 shows the status of the seismic stations for the day in question. Future Web pages will also include a map display of station status for the entire IMS Network, a threshold monitoring map, as well as displays of IDC Processing Status in terms of WorkFlow, Link Status, Database Status, AutoDRM Status, etc.

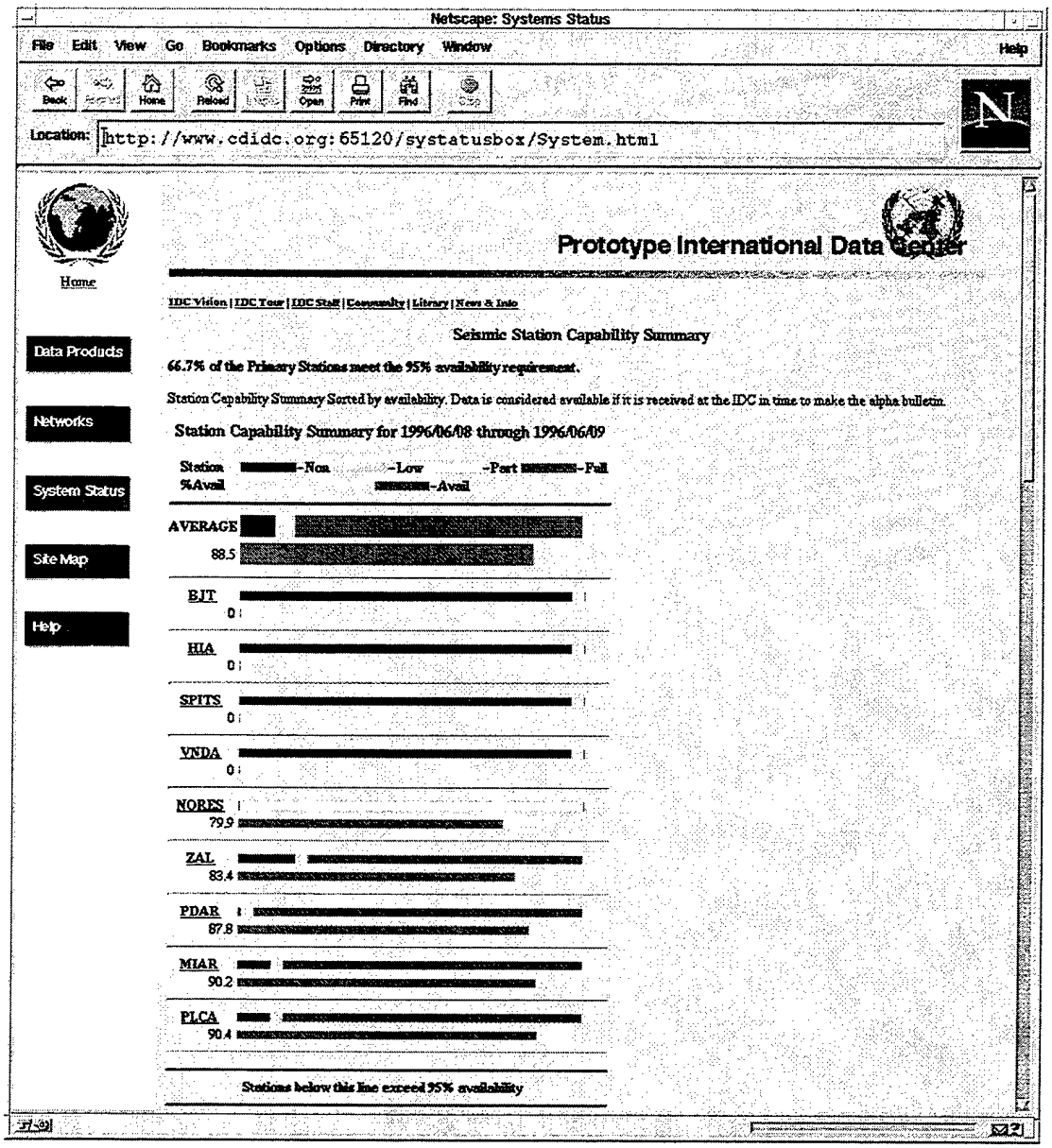


Figure 13. Seismic station status information for 8 June 1996.

Clicking on the boxes shown in Figure 12, which contain the numbers of events (*Total Worldwide, Total Considered, Not Screened* and those with *Insufficient Data*), displays Web pages providing corresponding *Event Lists*. Figure 14, for example, shows a map depicting the locations of all reviewed events detected on 8 June 1996. Figure 15 shows a corresponding table (below the map), which summarizes the events detected in various quadrants, and broken down by the particular monitoring technique(s) responsible for detecting, locating and characterizing the events. Below the table is a list of origin information for each event. A similar Web page, containing information about only the events which were, e.g., *Not Screened Out*, can be viewed by clicking on the corresponding box on the *Executive Summary* page.

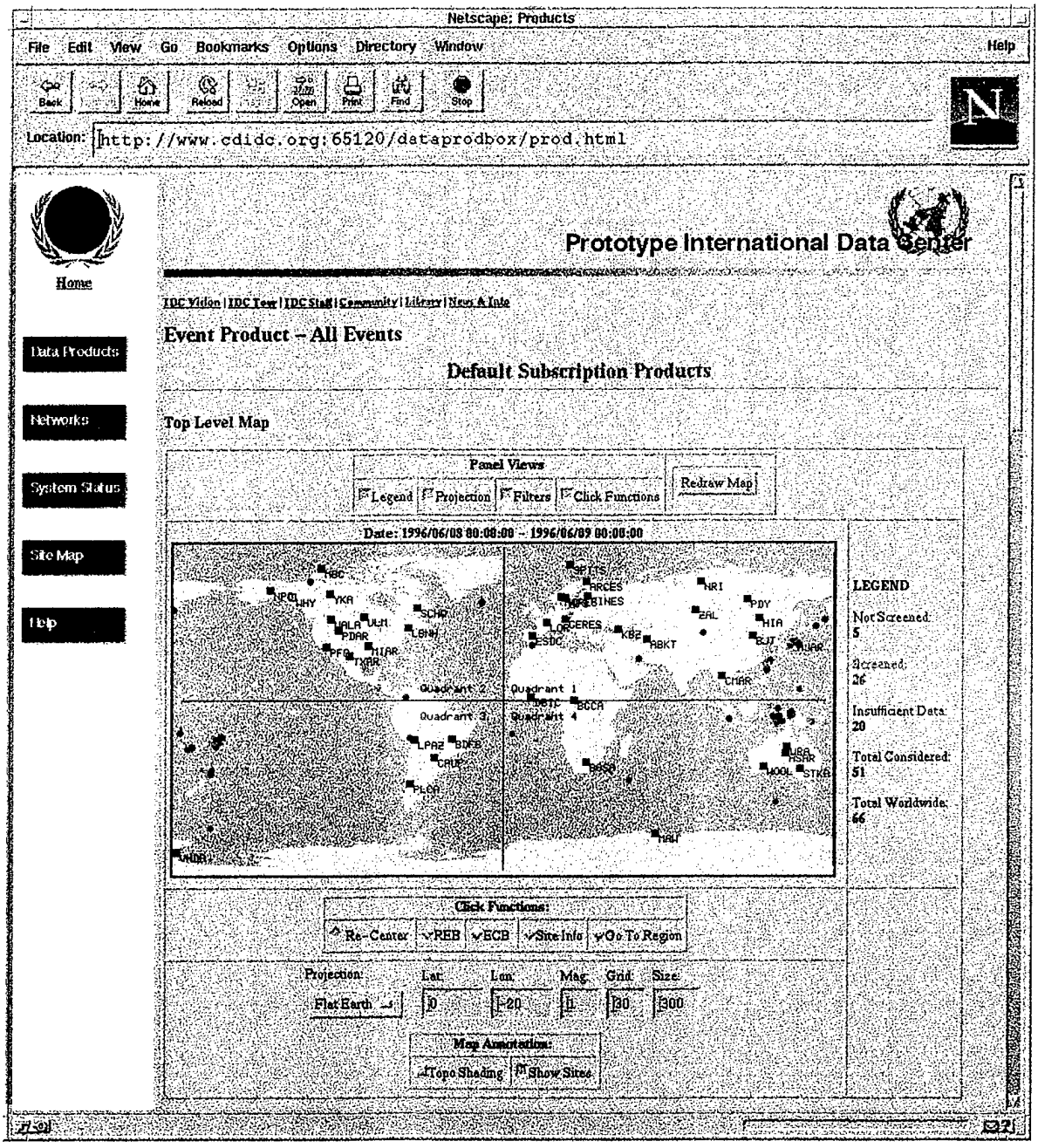


Figure 14. *Event List* page with a map display of events which occurred on 8 June 1996.

From the *Event List* page, there are hyperlinks (both on the map and in the event listing itself) to the *REB* and *ECB* Web pages. The *REB* provides detailed bulletin information regarding the various measurements used in detecting, associating and locating a given event, while the *ECB* provides in-depth information regarding the event characterization measurements and results of screening analyses. The bulletins provide hyperlinks to displays of the parameters, station information and, eventually, to the raw data.

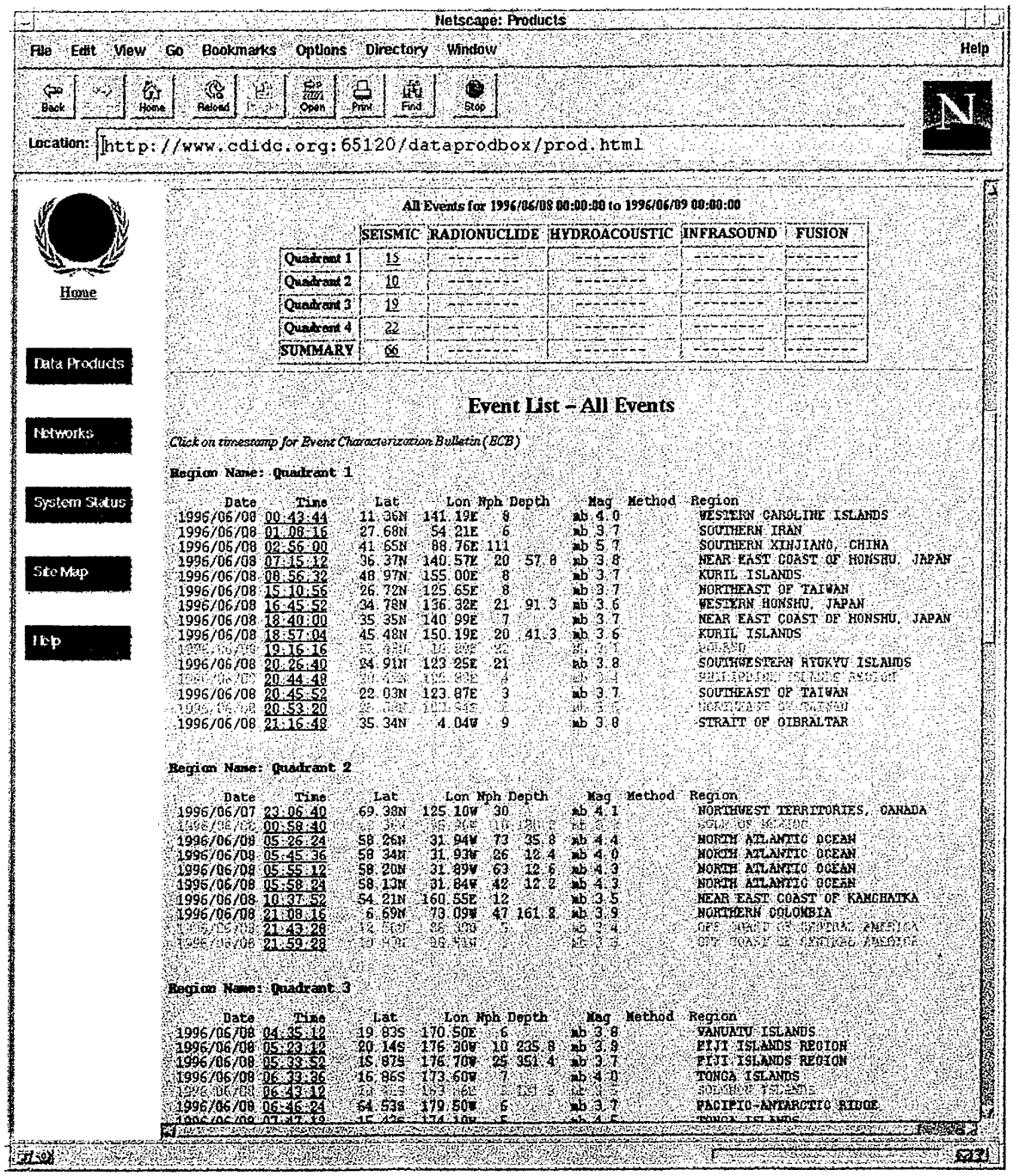


Figure 15. Event List for 8 June 1996. Listings are color-coded by whether the event was screened (green), not screened (red), had insufficient data to perform the screening tests (blue), or was not considered in the screening analyses (gray).

For example, Figure 16 shows the *ECB* for the underground nuclear explosion conducted at the Lop Nor test site in China on 8 June 1996. The event is highlighted by a circle on the map. The event characterization parameters and results of the screening analyses are given below the map.

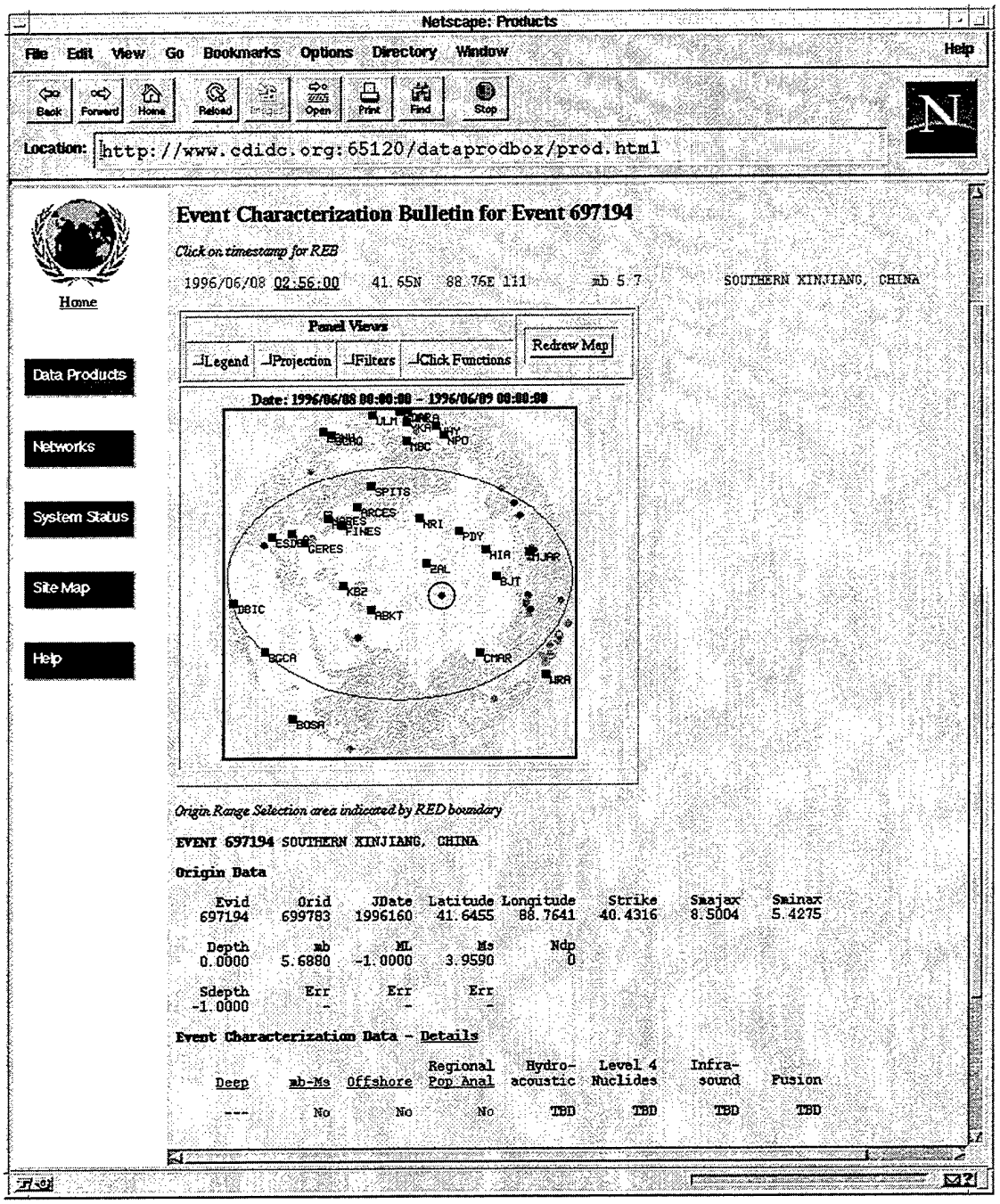


Figure 16. ***Event Characterization Bulletin (ECB)*** **for the Lop Nor underground nuclear test on 8 June 1996.**

Further information regarding results of the screening tests may be obtained by clicking on the "Details" hyperlink. By clicking on the "mb-Ms" hyperlink at the bottom of the page in Figure 16, e.g., a plot of mb-Ms versus mb is displayed for the events which occurred on this day, with the mb-Ms value for this event highlighted by a circle (Figure 17). Also shown are the 99% confidence intervals for mb-Ms. This and other similar displays allow the user to better understand the results.

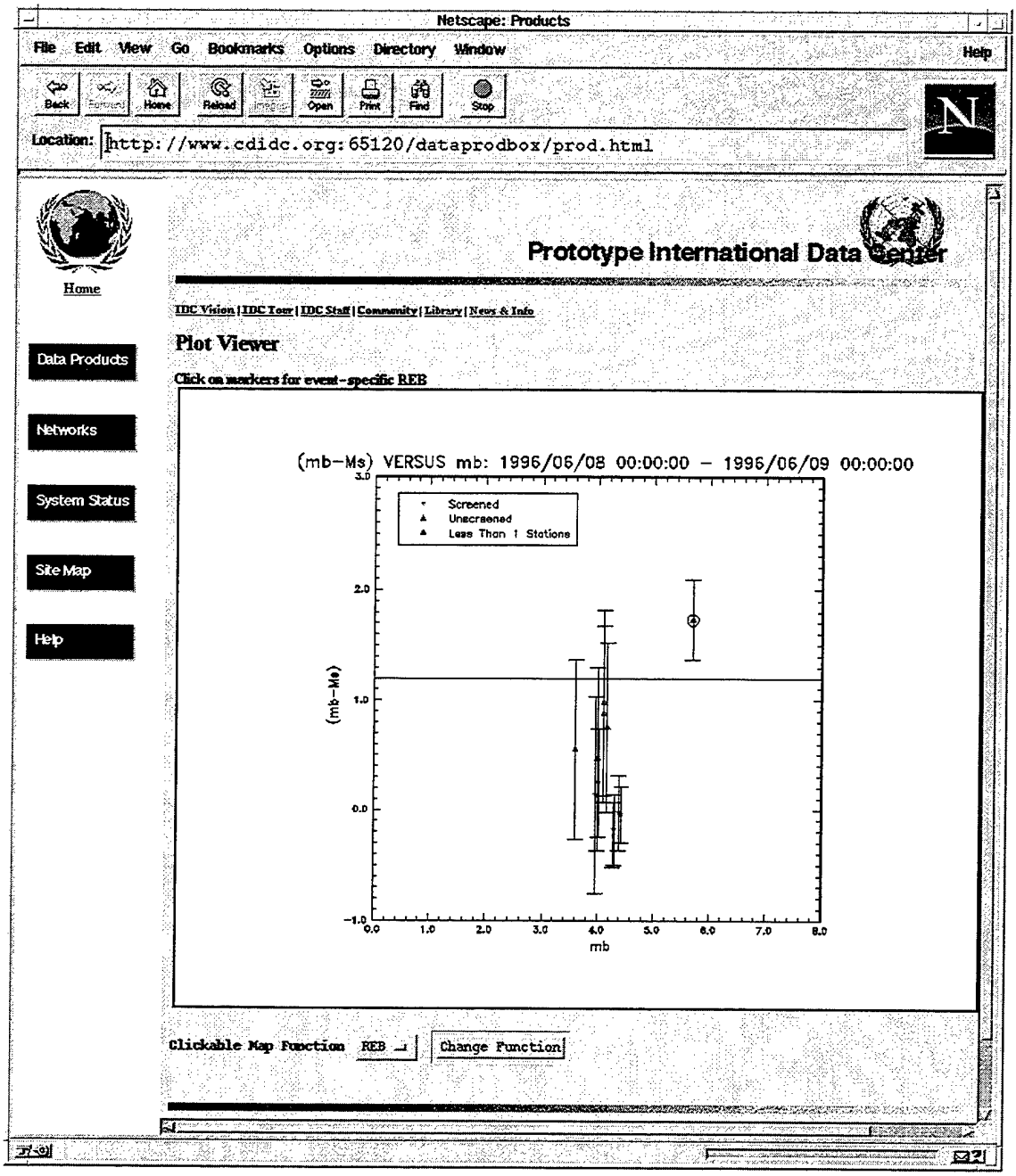


Figure 17. Display of mb-Ms versus mb, with 99% confidence intervals, for events that occurred on 8 June 1996. The mb-Ms value for the Lop Nor nuclear explosion is highlighted by the circle. Its entire 99% confidence interval is above the threshold set at 1.2.

The event characterization products presented in this section thus far have been based on a standard or default set of event screening criteria. In the following subsection we describe our development efforts to allow PIDC users to customize these data products.

3.2. Custom Subscription Service

We are developing a custom subscription service to allow authorized IDC users to establish regions of interest and custom event screening criteria. This is part of the larger subscription service being developed for IDC users so that they may obtain user-specific data products on a routine basis via either e-mail, ftp or the World Wide Web.

The Web version of the event characterization subscription form is shown in Figure 18. The first text box in the upper left of the form is for the *Subscription Name*, corresponding to authorized IDC users such as National Data Centers. In this example, the *Subscription Name* is New Zealand. On the same line there are buttons which allow new regions to be added or existing ones to be deleted. Associated with each region is a name. The default is *Region N*, where N is an integer. The region name may be edited in the corresponding text box as desired. Below this line are a set of text boxes which allow the user to define the latitude and longitude range of the region, as well as a magnitude range of interest. In this example, the magnitude range includes all events up to mb 8.

The second set of text boxes correspond to event screening criteria based on the depth, mb-Ms and offshore/onshore analyses. The user may set thresholds and confidence levels for defining an event as deep and whether it should be screened out based on mb-Ms. The user can also specify a confidence level associated with determining whether an event is offshore. The user may further set a minimum number of stations required with mb and Ms measurements before the mb-Ms analysis is performed. The user may also require the detection of one or more depth phase before screening out an event as being deep.

The third section of the form allows the user to select event characterization parameters for the regional population analysis. Also included are text boxes which allow the user to set a SNR criterion, a magnitude cut-off, a minimum training set size and the significance level of the test. These criteria allow the user to control the input and data quality for the regional analysis.

The user may specify different screening criteria for various regions, or even for multiple cases for the same region, if desired. Once the desired regions and criteria have been set, the user clicks on the "*Submit Parameter Modifications*" button at the bottom of the page to submit the form.

Much of the software to log and execute the subscriptions is still in the development stage. However, we plan to have a preliminary version installed by the end of 1996. Future work will include extensions to other seismic and non-seismic event characterization parameters and associated screening criteria.

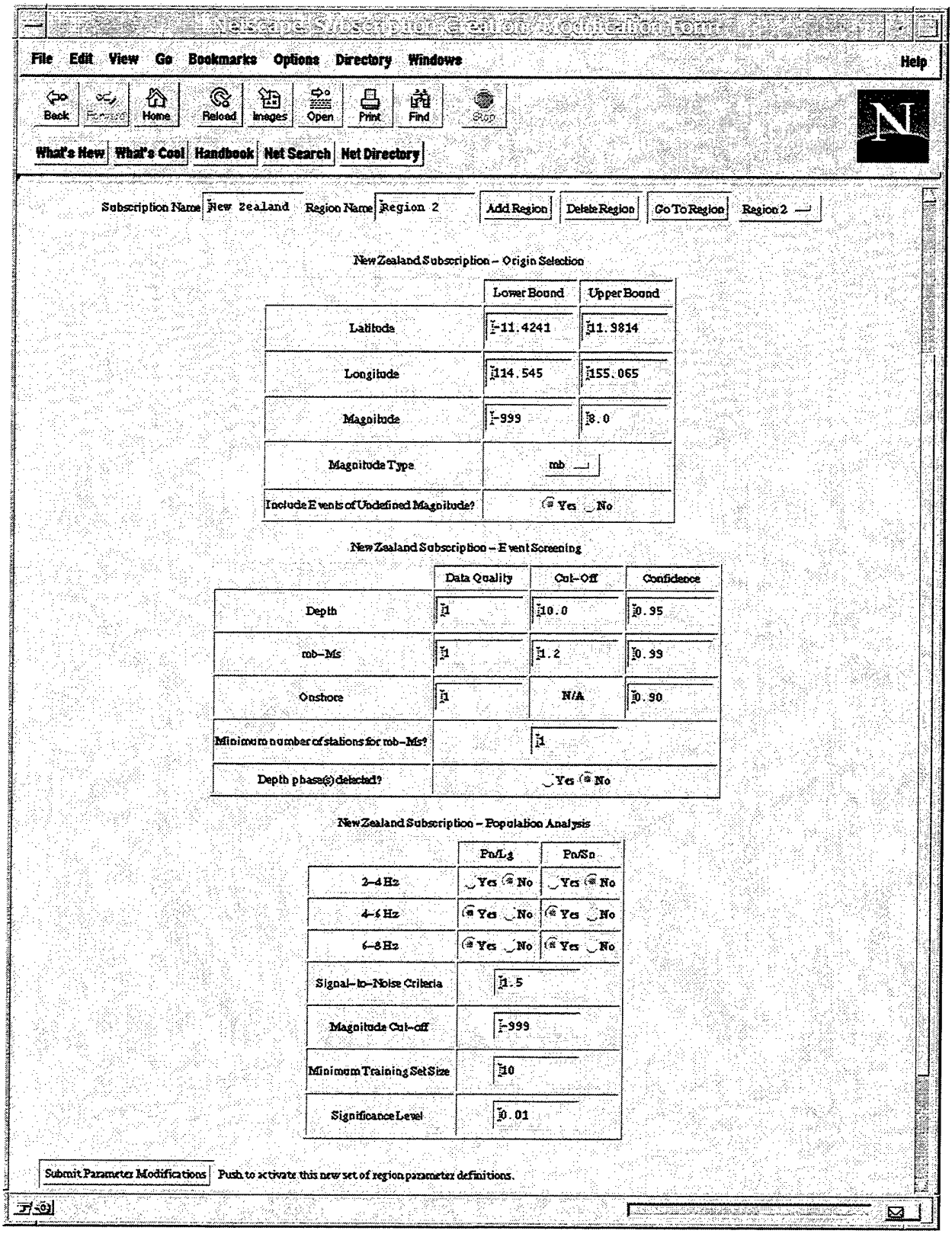


Figure 18. Subscription form to set up user-specified regions of interest and custom event screening criteria.

4. Preliminary Assessment of Event Characterization Capability

Using GSETT-3 data from the current (at the time this report was written) Primary seismic network, we have performed a preliminary assessment of the availability of useful event characterization data and the utility of the screening tools. The analyses were applied to events in the *Reviewed Event Bulletin (REB)* which occurred from 1 January 1996 to 31 August 1996. We used a standard set of screening criteria, as described in Section 3, and compiled monthly statistics on the numbers and percentages (relative to the total per month) of events that were placed in various screening categories, including those that could or could not be analyzed, based on available event characterization parameters.

Figures 19 and 20 show, on a monthly basis, the numbers and percentages, respectively, of events which were placed in the various screening categories, i.e., *Considered, Insufficient Data, Screened* and *Not Screened*. The screening criteria used to obtain these results are given in Table 2.

Table 2. Summary of event screening criteria used in this analysis.

Event Screening Category	Criteria
Considered	Events of mb 3.5 or greater
Insufficient Data	Insufficient data with which to apply any of the depth, mb-Ms or regional population analyses
Screened	90% location error ellipse entirely offshore, or 95% depth confidence interval entirely deeper than 10 km, or 99% mb-Ms confidence interval entirely less than 1.2, or Regional Population Analysis P-value > 0.01
Not Screened	Events with sufficient event characterization data, which do not satisfy any of the criteria to be *Screened.*

Initially, the event screening tools utilized only seismic estimates of location, depth, mb-Ms, and their uncertainties, based on the availability of relevant parameters. On 10 July 1996, a code to compute high-frequency regional amplitudes was integrated into the processing pipeline at the PIDC. Shortly thereafter, we established regional training sets for 16 Primary GSETT-3 seismic stations (ARCES, ASAR, CMAR, ESDC, FINES, GERES, HFS, LOR, LPAZ, MJAR, NORES, PDAR, SPITS, TXAR, WRA and ZAL), for which there were sufficient data. Thus, the regional population analysis could be applied only to events which occurred on 10 July 1996 or after, and only to events for which there were regional amplitudes (Pn, Sn and Lg) computed for stations with regional training sets.

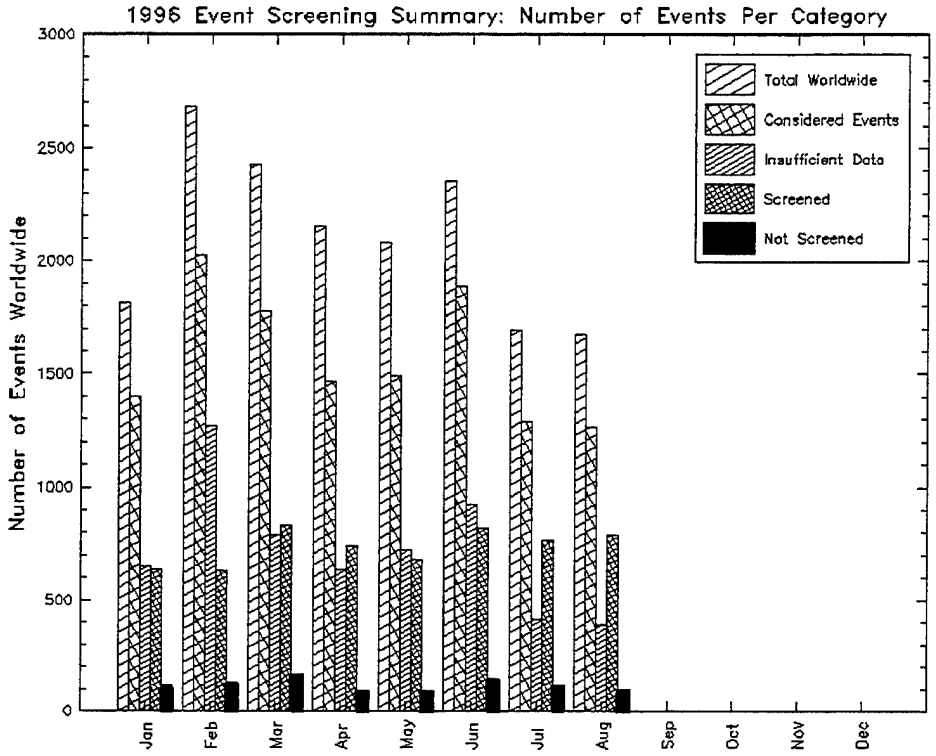


Figure 19. Number of events by category (Total, Considered, Insufficient Data, Screened and Not Screened), plotted by month from January through August 1996.

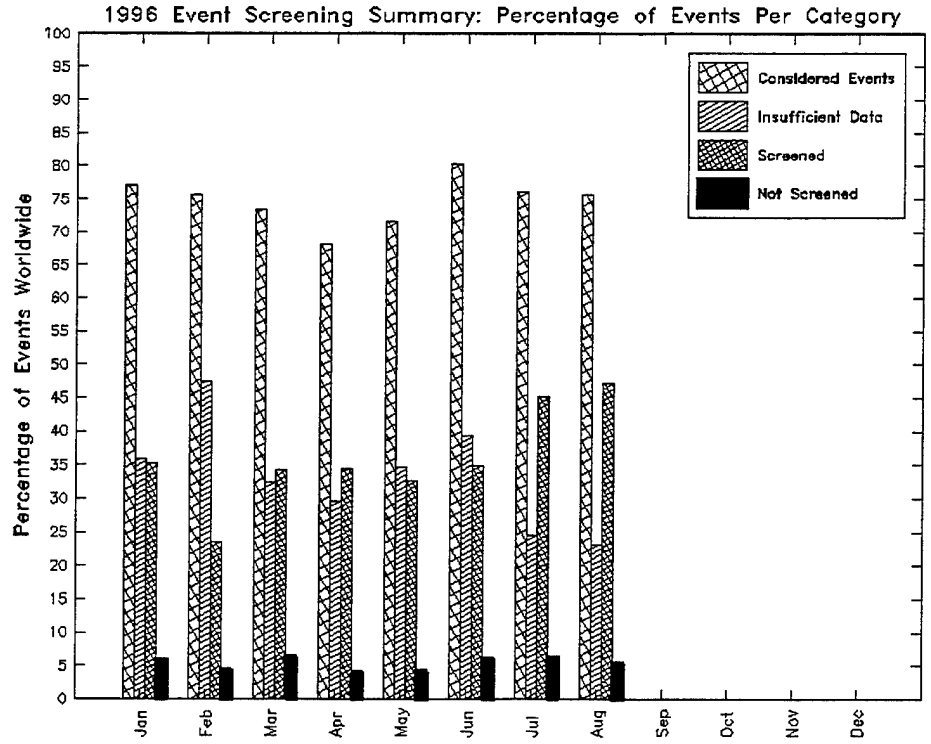


Figure 20. Percentage of events by screening category, plotted by month from January through August 1996.

There were roughly 1700 to 2700 events per month, after analyst review, of which roughly 70% to 80% were mb 3.5 or above. The variation in the number of events per month is due to variations in seismic activity, as well as variations in the number of GSETT-3 stations which were on-line during this period (cf. IDC Performance Reports). Between January and June of 1996, there were nearly equal percentages (roughly 30% to 40%) of events with insufficient data as those that were screened, with the notable exception of February 1996, for which there were nearly twice as many events with insufficient data than those that were screened.

The unusually large number of events during February was primarily due to a large earthquake sequence, with roughly 600 detected aftershocks, off the northwest coast of New Guinea. This sequence began on 17 February 1996 and lasted nearly five days, including 353 events reported in the *REB* on February 17 (IDC Performance Report, 15 March 1996). Of these events, 34% included Auxiliary data. Most of these events had depth estimates constrained to the surface, location error ellipses too large to place the events in the offshore category at the 90% confidence level, and no Ms or regional high-frequency amplitude measurements. Hence, this lead to an unusually large percentage of events categorized as having insufficient event characterization data.

Starting in July 1996, there was a noticeable improvement in screening performance, in terms of a reduction in the percentage of events with insufficient data and an increase in the percentage of screened events (Figure 20). The percentage of screened events increased to roughly 45%, now nearly twice the rate of events with insufficient data. This was a direct result of regional amplitudes being computed at this time and the regional population analysis being executed for a set of 16 stations, less than 14% of the existing Primary and Auxiliary Network and roughly 10% of the total proposed IMS Network of 50 Primary and 120 Auxiliary seismic stations.

This improvement was rather dramatic and encouraging, despite the relatively small percentage of stations with regional training sets. Thus, comparable improvements in performance should be expected as the full set of IMS seismic stations come on-line and as regional training sets are established for the remaining Primary and Auxiliary stations.

Roughly 5% of the events per month were categorized as *Not Screened.* These were primarily events with depth and/or mb-Ms measurements, but the uncertainties in the measurements were such that the events could not be screened at the specified confidence levels.

In the future, we plan to establish a more complete set of performance metrics, as well as a set of operational procedures for analyzing both interesting and routine events, in order to measure

progress in event screening performance, including assessment of the data quality and the accuracy of the results. In particular, we plan to quantify the percentage of events that are placed in the various categories by individual and combined screening criteria, and as functions of magnitude, number of defining phases, station(s), region, SNR and other relevant measures. These metrics should indicate how many events can be analyzed using available data, as a function of IMS Network coverage, how many can be screened by the various tests and, as illustrated, how upgrades to the event characterization procedures affect the performance. We also plan to establish interactive analysis procedures in order to validate computations of the event characterization parameters and the screening results. Last, we plan to assess the sensitivity of the results to variations in the screening criteria (e.g., cut-offs and confidence levels). This information will help PIDC users make informed selections of input parameters for custom screening analyses.

5. Event Characterization for Two 1996 Nuclear Tests at Lop Nor

Two underground nuclear tests were conducted on 8 June and 29 July 1996 at the Lop Nor test site in China. These events were among a larger set of events in Eurasia during this time period, and provide a useful test of the event characterization software. The orthographic map in Figure 21 shows locations of seismic events which occurred between 1 June and 31 July 1996 in the region defined by a latitude range from +15° (degrees) to +60° and a longitude range from +45° to +120°, as indicated by the enclosed region on the map. Only the events in this region for which mb-Ms and/or high-frequency regional amplitude ratios were computed were considered in this study. There were a total of 19 events in this region, during this period, with mb-Ms and/or regional amplitude ratios for station Zalesovo (ZAL), located at 53.62 latitude and 84.79 longitude in the Russian Federation, and/or station Nilore (NIL), located at 33.65 latitude and 73.25 longitude in Pakistan. These events were analyzed using the event screening tools for focal depth, mb-Ms and regional population analysis, which are currently available at the PIDC.

Based on analyst-reviewed processing at the PIDC, the 960608 Lop Nor event occurred at approximately 02:56:00 UTC, 41.65° latitude and 88.76° longitude, and the 960729 Lop Nor event occurred at approximately 01:48:48 UTC, 41.69° latitude and 88.35° longitude. Both events were approximately 12.2° from station ZAL and 14.4° from station NIL. The focal depths for both of these events were constrained to the surface. The 960608 Lop Nor event had magnitude estimates of mb 5.7 and Ms 4.0. The 960729 Lop Nor event was mb 4.7, but did not have an Ms measurement. Thus, the mb-Ms analysis could not be applied to this event.

Figure 22 shows a plot of mb-Ms values versus mb for the events with relevant measurements. The error bars depict the 99% confidence intervals for mb-Ms. The event with the highest mb-Ms estimate (equal to 1.7) on this plot corresponds to the 960608 Lop Nor underground nuclear explosion. Hence, it was placed in the *Not Screened* category, based on an mb-Ms threshold of 1.2. For one event, the entire 99% confidence interval for mb-Ms was less than 1.2. Hence, it was screened. Two other events had mb-Ms values less than 1.2, but the entire 99% confidence intervals were not less than 1.2. Hence, these events were not screened based on mb-Ms.

The 960729 Lop Nor event had regional amplitudes for both stations ZAL and NIL, while regional amplitudes for the 960608 Lop Nor event were computed, by hand, only for station NIL. Figure 23 shows plots of Pn/Lg (left) and Pn/Sn (right) in three frequency bands (2-4 Hz, 4-6 Hz and 6-8 Hz) for events recorded by station NIL. The values for the Lop Nor explosions are depicted by the red asterisks and are considerably higher than the corresponding values for the other events.

Figure 24 shows a plot of the regional population analysis results for station NIL, using Pn/Lg and Pn/Sn in the 4-6 and 6-8 Hz bands. All but the two Lop Nor nuclear explosions were found to be consistent with the population of events in this region at the 0.01 significance level. Both the Lop Nor explosions were found to be outliers at the 0.01 significance level. The 960729 event was also found to be an outlier at station ZAL.

In summary, of the 19 events, one event (1996/07/19, 02:29:20, 39.74N, 54.01E, mb 4.6, TURKMENISTAN) was screened by depth, one event (1996/07/24, 17:24:16, 35.91N, 68.50E, mb 5.0, HINDU KUSH REGION, AFGHANISTAN) was screened by mb-Ms, and all events, except the two Lop Nor nuclear explosions, were found to be consistent with the population of seismic events in this region, based on regional high-frequency measurements of Pn/Lg and Pn/Sn.

Both the 960608 and 960729 Lop Nor events had focal depths constrained to the surface. The 960608 Lop Nor event has a 99% confidence interval for mb-Ms entirely above the threshold of 1.2. No Ms measurements were available for the 960729 Lop Nor event. Both the 960608 and 960729 Lop Nor events were flagged as outliers, based on the regional population analysis, using regional high-frequency measurements of Pn/Lg and Pn/Sn and a 0.01 significance level. Hence, both of the Lop Nor nuclear explosions were placed in the *Not Screened* category. This example illustrates how the event screening software at the PIDC can be used to flag anomalous events for further interactive review.

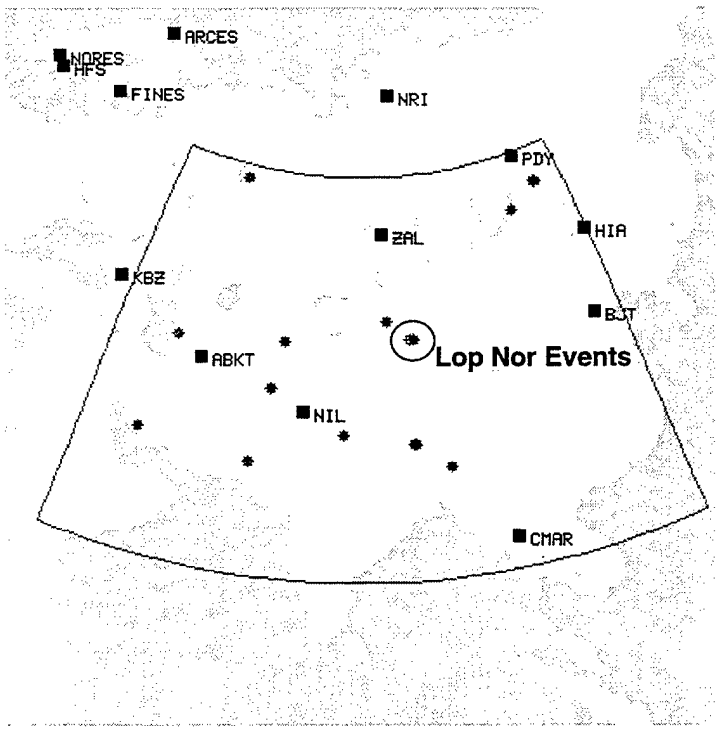


Figure 21. Map (orthographic projection) depicting the locations of stations and seismic events considered in this study. The locations of the two Lop Nor underground explosions are indicated.

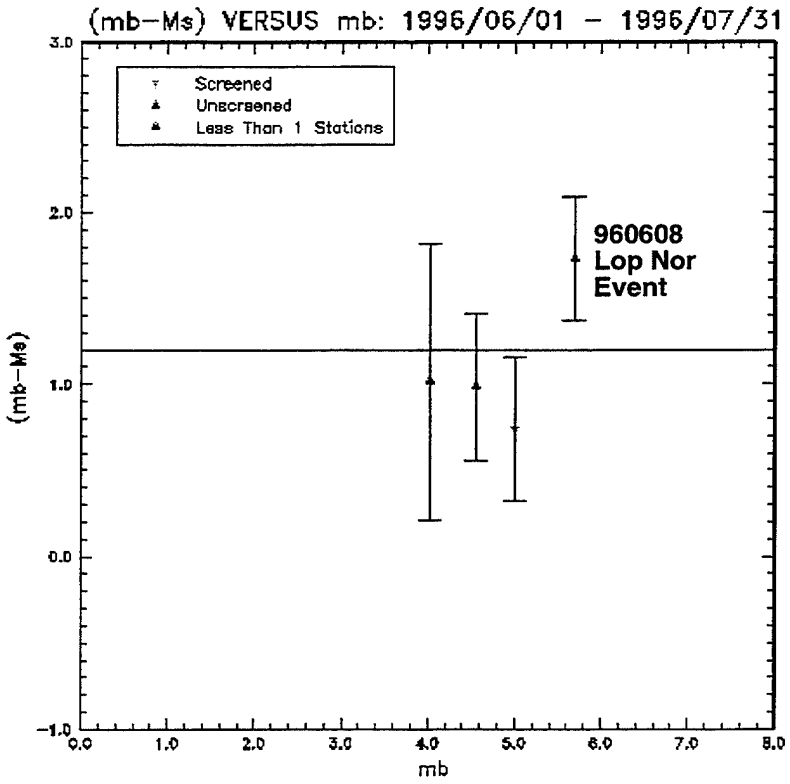


Figure 22. Plot of mb-Ms values versus mb, with 99% confidence intervals indicated by the error bars.

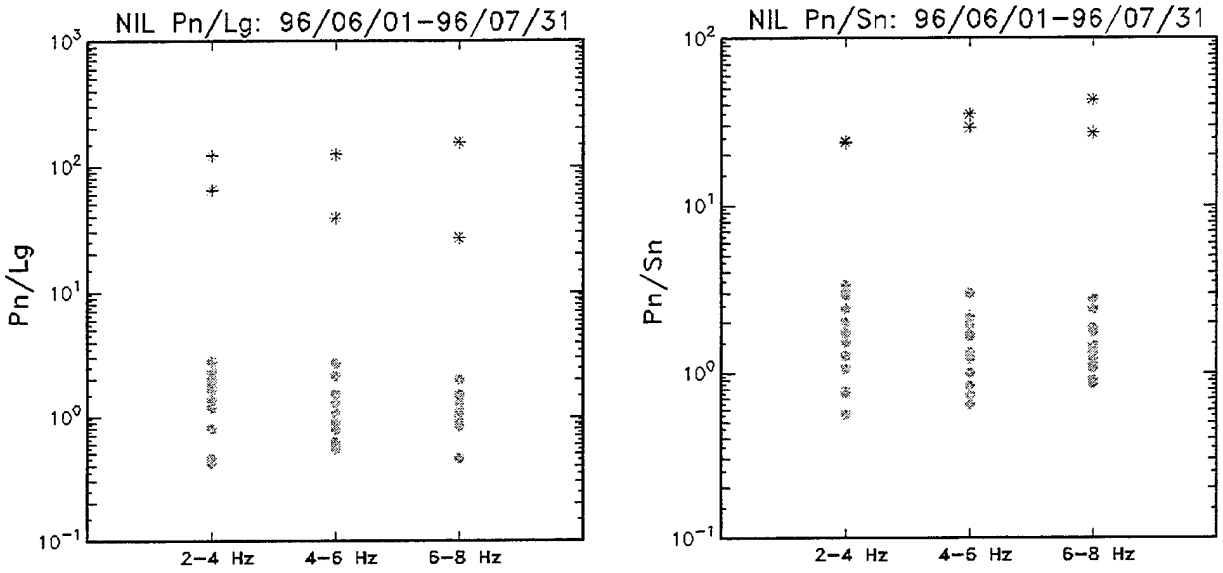


Figure 23. **Plots of Pn/Lg (left) and Pn/Sn (right) in three frequency bands for the events recorded by station NIL. The values for the Lop Nor explosions are depicted by the red asterisks.**

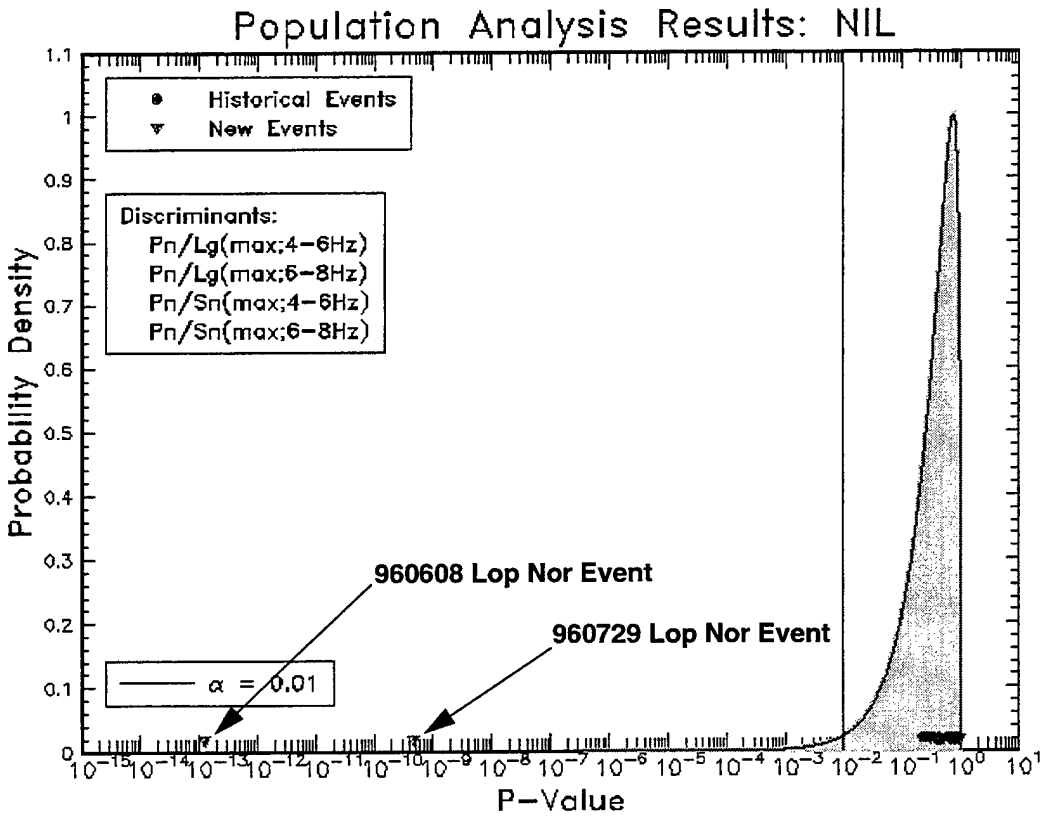


Figure 24. **Regional population analysis results for the events recorded by station NIL. Both of the Lop Nor underground nuclear tests are found to be outliers at the 0.01 significance level.**

6. Conclusions and Recommendations

We described the interactive and automated event screening analyses which are currently installed at the PIDC, as well as the Web pages we have implemented to make these tools and related data products accessible to remote users. We presented two basic services: (1) an interactive event screening service which allows custom criteria to be provided and applied during an on-line session; and (2) a subscription service utilizing either a default or custom (user-specified) set of screening criteria that remain in affect until they are changed by the user. These Web pages currently provide a preliminary capability for users to select and screen events based on user-defined criteria, and to view and download event characterization data products over the Internet.

Current implementations have focused on analysis of seismic events. However, future versions of the PIDC Web pages will also reflect event characterization data and screening analyses for hydroacoustic, infrasound, radionuclide and fusion techniques, as well as for new seismic analyses. We also plan to develop dissemination services, via e-mail and ftp, for the event characterization products as part of the integrated subscription/request service being developed at the PIDC.

We further presented screening results, using GSETT-3 data collected from existing Primary seismic stations. In Section 2, we showed how the interactive Web pages could be used to analyze a set of events using custom screening criteria. In the example shown, there were 1859 events world-wide from 15 July to 16 August 1996, of which 1434 were mb 3.5 or larger. Of these, 30% had *insufficient data* with which to perform the screening tests, 65% were *screened out*, and 5% were *not screened*. Included in the set of events that were *not screened* was the 960729 Lop Nor underground nuclear test. The example illustrated how the interactive screening tools can be used to reduce the number of seismic events to a more manageable number for further investigation.

In Section 3, we presented a set of standard event characterization data products, computed on an automated basis. (We further described the subscription service we are implementing to allow users to define regions of interest and customize their screening criteria.) On 8 June 1996, there were 65 events, of which 51 were mb 3.5 or larger. Of the 51 events, 20 had *insufficient* event characterization data, 26 were *screened out*, and 5 were *not screened*, based on the screening criteria. Included in the 5 events that were not screened on that day was the 960608 Lop Nor nuclear explosion. Figure 17 shows that 4 of these 5 events had mb-Ms values less than 1.2, but the 99% mb-Ms confidence intervals were not entirely below the line. (Less stringent criteria could be used, if desired specific users. Note also that the regional event characterization analyses had not yet been installed at this time.) This case illustrates how a user could examine these summaries and associated graphics on a regular basis to focus on anomalous events.

In Section 4, we presented a preliminary assessment of the event characterization capability over time, in terms of the numbers/percentages of events placed in various screening categories. Starting in July 1996, there was a significant reduction in the percentage with *insufficient data*, due to integration of codes to process regional amplitudes and perform the regional population analysis, despite the fact that regional training sets were established for only a small percentage of stations.

In Section 5, we examined in more detail a set of events in Eurasia, including two Lop Nor underground nuclear explosions. The results showed that, provided there were measurements of mb-Ms or regional amplitude ratios, the event screening tools were very effective, in this region, in screening out all of the events except the two known nuclear explosions.

Despite the significant progress in implementing event characterization capabilities at the PIDC, considerable work remains to improve the performance. The IMS Network is still incomplete and event characterization processing capabilities at the PIDC are still in the development stage, particularly for the non-seismic monitoring technologies. Currently we have regional training sets for only 17 seismic stations, 10% of the Primary and Auxiliary stations in the future IMS Network. As the full set of stations come on-line, and as more regional data become available over time, we plan to continue our efforts to establish regional distance corrections and training sets. (We will describe this work in a future report.) We expect that this will eventually reduce the number of events with insufficient event characterization data to a much smaller percentage.

Codes to compute additional event characterization parameters are also being integrated at the PIDC. This should further aid in screening a higher percentage of the events in the future. New seismic parameters include complexity, spectral variance, 2-D cepstral features, a short-period to long-period energy ratio, autoregressive Lg analysis, and others. The efficacy of these parameters needs to be investigated for various regions. Parameters that reliably distinguish mining blasts from other types of events are needed to permit useful event screening analyses for events below mb 3.5. Event characterization parameters and screening capabilities, based on hydroacoustic and infrasound data, must also be implemented to monitor oceanic and atmospheric regimes.

We also plan to establish additional metrics to better quantify event screening performance, including data quality, accuracy of the results, and progress over time. In particular, we plan to quantify dependencies on magnitude, network coverage, region, and other relevant measures. We also plan to establish procedures for interactive review to validate the analyses. Last, we plan to assess the sensitivity of the results to variations in the screening criteria. This information will help PIDC users make informed selections of input parameters for custom screening analyses.

References

Baek, J., H. L. Gray, and W. A. Woodward, J. Miller and M. D. Fisk (1996). A Bootstrap Generalized Likelihood Ratio Test in Discriminant Analysis, *Comp. Stat. Data Anal.*, **22,** 137-158.

Bottone, S., M.D. Fisk, H.L. Gray and G.D. McCartor (1996). The Dependence of Magnitude Uncertainty on Station Coverage, PL-TR-96-2250, Phillips Laboratory, Hanscom AFB, MA.

Fisk, M.D. (1996). World Wide Web Pages for Custom Event Screening at the Prototype International Data Center, GSE/WGO/Informal 3, February, 1996.

Fisk, M.D., H.L. Gray and G.D. McCartor (1996). Regional discrimination without transporting thresholds, *Bull. Seism. Soc. Am.*, **86**, 1545-1558.

Fisk, M.D., H.L. Gray and G.D. McCartor (1995). Statistical Methodology and Assessment of Seismic Event Characterization Capability, PL-TR-95-2156, Phillips Laboratory, Hanscom AFB, MA, ADA305487.

Fisk, M.D., H.L. Gray and G.D. McCartor (1994). Preliminary Assessment of CTBT/NPT Monitoring Capability, PL-TR-94-2300, Phillips Laboratory, Hanscom AFB, MA, ADA293188.

Fisk, M.D., H.L. Gray and G.D. McCartor (1993). Applications of Generalized Likelihood Ratio Tests to Seismic Event Identification, PL-TR-93-2221, Phillips Laboratory, Hanscom AFB, MA, ADA279479.

GSE/CRP/243 (1995). Group of Scientific Experts - Conference Room Paper, 243, Available through the Center for Monitoring Research, Arlington, VA.

IDC Performance Report - February 11 to March 9, 1996 (March 15, 1996). Available through the Center for Monitoring Research, Arlington, VA.

Jepsen, D. and M.D. Fisk (1996). Progress Report on Event Characterization at the IDC, GSE/WGO/17, May, 1996.

THOMAS AHRENS
SEISMOLOGICAL LABORATORY 252-21
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CA 91125

SHELTON ALEXANDER
PENNSYLVANIA STATE UNIVERSITY
DEPARTMENT OF GEOSCIENCES
537 DEIKE BUILDING
UNIVERSITY PARK, PA 16801

RICHARD BARDZELL
ACIS
DCI/ACIS
WASHINGTON, DC 20505

DOUGLAS BAUMGARDT
ENSCO INC.
5400 PORT ROYAL ROAD
SPRINGFIELD, VA 22151

WILLIAM BENSON
NAS/COS
ROOM HA372
2001 WISCONSIN AVE. NW
WASHINGTON, DC 20007

ROBERT BLANDFORD
AFTAC
1300 N. 17TH STREET
SUITE 1450
ARLINGTON, VA 22209-2308

RHETT BUTLER
IRIS
1616 N. FORT MEYER DRIVE
SUITE 1050
ARLINGTON, VA 22209

CATHERINE DE GROOT-HEDLIN
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UNIVERSITY OF CALIFORNIA, SAN DIEGO
INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
LA JOLLA, CA 92093

SEAN DORAN
ACIS
DCI/ACIS
WASHINGTON , DC 20505

RICHARD J. FANTEL
BUREAU OF MINES
DEPT OF INTERIOR, BLDG 20
DENVER FEDERAL CENTER
DENVER, CO 80225

RALPH ALEWINE
NTPO
1901 N. MOORE STREET, SUITE 609
ARLINGTON, VA 22209

MUAWIA BARAZANGI
INSTITUTE FOR THE STUDY OF THE CONTINENTS
3126 SNEE HALL
CORNELL UNIVERSITY
ITHACA, NY 14853

T.G. BARKER
MAXWELL TECHNOLOGIES
P.O. BOX 23558
SAN DIEGO, CA 92123

THERON J. BENNETT
MAXWELL TECHNOLOGIES
11800 SUNRISE VALLEY DRIVE SUITE 1212
RESTON, VA 22091

JONATHAN BERGER
UNIVERSITY OF CA, SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY IGPP, 0225
9500 GILMAN DRIVE
LA JOLLA, CA 92093-0225

STEVEN BRATT
NTPO
1901 N. MOORE STREET, SUITE 609
ARLINGTON, VA 22209

LESLIE A. CASEY
DOE
1000 INDEPENDENCE AVE. SW
NN-40
WASHINGTON, DC 20585-0420

STANLEY DICKINSON
AFOSR
110 DUNCAN AVENUE, SUITE B115
BOLLING AFB
WASHINGTON, D.C. 20332-001

DIANE I. DOSER
DEPARTMENT OF GEOLOGICAL SCIENCES
THE UNIVERSITY OF TEXAS AT EL PASO
EL PASO, TX 79968

JOHN FILSON
ACIS/TMG/NTT
ROOM 6T11 NHB
WASHINGTON, DC 20505

MARK D. FISK
MISSION RESEARCH CORPORATION
735 STATE STREET
P.O. DRAWER 719
SANTA BARBARA, CA 93102-0719

LORI GRANT
MULTIMAX, INC.
311C FOREST AVE. SUITE 3
PACIFIC GROVE, CA 93950

I. N. GUPTA
MULTIMAX, INC.
1441 MCCORMICK DRIVE
LARGO, MD 20774

JAMES HAYES
NSF
4201 WILSON BLVD., ROOM 785
ARLINGTON, VA 22230

MICHAEL HEDLIN
UNIVERSITY OF CALIFORNIA, SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY IGPP, 0225
9500 GILMAN DRIVE
LA JOLLA, CA 92093-0225

EUGENE HERRIN
SOUTHERN METHODIST UNIVERSITY
DEPARTMENT OF GEOLOGICAL SCIENCES
DALLAS, TX 75275-0395

VINDELL HSU
HQ/AFTAC/TTR
1030 S. HIGHWAY A1A
PATRICK AFB, FL 32925-3002

RONG-SONG JIH
PHILLIPS LABORATORY
EARTH SCIENCES DIVISION
29 RANDOLPH ROAD
HANSCOM AFB, MA 01731-3010

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-200
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-221
LIVERMORE, CA 94551

ROBERT GEIL
DOE
PALAIS DES NATIONS, RM D615
GENEVA 10, SWITZERLAND

HENRY GRAY
SMU STATISTICS DEPARTMENT
P.O. BOX 750302
DALLAS, TX 75275-0302

DAVID HARKRIDER
PHILLIPS LABORATORY
EARTH SCIENCES DIVISION
29 RANDOLPH ROAD
HANSCOM AFB, MA 01731-3010

THOMAS HEARN
NEW MEXICO STATE UNIVERSITY
DEPARTMENT OF PHYSICS
LAS CRUCES, NM 88003

DONALD HELMBERGER
CALIFORNIA INSTITUTE OF TECHNOLOGY
DIVISION OF GEOLOGICAL & PLANETARY SCIENCES
SEISMOLOGICAL LABORATORY
PASADENA, CA 91125

ROBERT HERRMANN
ST. LOUIS UNIVERSITY
DEPARTMENT OF EARTH & ATMOSPHERIC SCIENCES
3507 LACLEDE AVENUE
ST. LOUIS, MO 63103

ANTHONY IANNACCHIONE
BUREAU OF MINES
COCHRANE MILL ROAD
PO BOX 18070
PITTSBURGH, PA 15236-9986

THOMAS JORDAN
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
EARTH, ATMOSPHERIC & PLANETARY SCIENCES
77 MASSACHUSETTS AVENUE, 54-918
CAMBRIDGE, MA 02139

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-207
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
LLNL
PO BOX 808, MS L-175
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-208
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-202
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-195
LIVERMORE, CA 94551

LAWRENCE LIVERMORE NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 808, MS L-205
LIVERMORE, CA 94551

THORNE LAY
UNIVERSITY OF CALIFORNIA, SANTA CRUZ
EARTH SCIENCES DEPARTMENT
EARTH & MARINE SCIENCE BUILDING
SANTA CRUZ, CA 95064

ANATOLI L. LEVSHIN
DEPARTMENT OF PHYSICS
UNIVERSITY OF COLORADO
CAMPUS BOX 390
BOULDER, CO 80309-0309

DONALD A. LINGER
DNA
6801 TELEGRAPH ROAD
ALEXANDRIA, VA 22310

LOS ALAMOS NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 1663, MS F659
LOS ALAMOS, NM 87545

LOS ALAMOS NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 1663, MS F665
LOS ALAMOS, NM 87545

LOS ALAMOS NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 1663, MS D460
LOS ALAMOS, NM 87545

LOS ALAMOS NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 1663, MS C335
LOS ALAMOS, NM 87545

GARY MCCARTOR
SOUTHERN METHODIST UNIVERSITY
DEPARTMENT OF PHYSICS
DALLAS, TX 75275-0395

KEITH MCLAUGHLIN
MAXWELL TECHNOLOGIES
P.O. BOX 23558
SAN DIEGO, CA 92123

BRIAN MITCHELL
DEPARTMENT OF EARTH & ATMOSPHERIC SCIENCES
ST. LOUIS UNIVERSITY
3507 LACLEDE AVENUE
ST. LOUIS, MO 63103

RICHARD MORROW
USACDA/IVI
320 21ST STREET, N.W.
WASHINGTON, DC 20451

JOHN MURPHY
MAXWELL TECHNOLOGIES
11800 SUNRISE VALLEY DRIVE SUITE 1212
RESTON, VA 22091

JAMES NI
NEW MEXICO STATE UNIVERSITY
DEPARTMENT OF PHYSICS
LAS CRUCES, NM 88003

JOHN ORCUTT
INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
UNIVERSITY OF CALIFORNIA, SAN DIEGO
LA JOLLA, CA 92093

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K6-48
RICHLAND, WA 99352

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K7-34
RICHLAND, WA 99352

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K6-40
RICHLAND, WA 99352

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K5-72
RICHLAND, WA 99352

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K5-12
RICHLAND, WA 99352

KEITH PRIESTLEY
DEPARTMENT OF EARTH SCIENCES
UNIVERSITY OF CAMBRIDGE
MADINGLEY RISE, MADINGLEY ROAD
CAMBRIDGE, CB3 OEZ UK

PAUL RICHARDS
COLUMBIA UNIVERSITY
LAMONT-DOHERTY EARTH OBSERVATORY
PALISADES, NY 10964

CHANDAN SAIKIA
WOOODWARD-CLYDE FEDERAL SERVICES
566 EL DORADO ST., SUITE 100
PASADENA, CA 91101-2560

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 6116
MS 0750, PO BOX 5800
ALBUQUERQUE, NM 87185-0750

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 9311
MS 1159, PO BOX 5800
ALBUQUERQUE, NM 87185-1159

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 5736
MS 0655, PO BOX 5800
ALBUQUERQUE, NM 87185-0655

THOMAS SERENO JR.
SCIENCE APPLICATIONS INTERNATIONAL
CORPORATION
10260 CAMPUS POINT DRIVE
SAN DIEGO, CA 92121

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K7-22
RICHLAND, WA 99352

PACIFIC NORTHWEST NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
PO BOX 999, MS K6-84
RICHLAND, WA 99352

FRANK PILOTTE
HQ/AFTAC/TT
1030 S. HIGHWAY A1A
PATRICK AFB, FL 32925-3002

JAY PULLI
RADIX SYSTEMS, INC.
6 TAFT COURT
ROCKVILLE, MD 20850

DAVID RUSSELL
HQ AFTAC/TTR
1030 SOUTH HIGHWAY A1A
PATRICK AFB, FL 32925-3002

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 5704
MS 0979, PO BOX 5800
ALBUQUERQUE, NM 87185-0979

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 5791
MS 0567, PO BOX 5800
ALBUQUERQUE, NM 87185-0567

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 5704
MS 0655, PO BOX 5800
ALBUQUERQUE, NM 87185-0655

SANDIA NATIONAL LABORATORY
ATTN: TECHNICAL STAFF (PLS ROUTE)
DEPT. 6116
MS 0750, PO BOX 5800
ALBUQUERQUE, NM 87185-0750

AVI SHAPIRA
SEISMOLOGY DIVISION
THE INSTITUTE FOR PETROLEUM RESEARCH AND
GEOPHYSICS
P.O.B. 2286, NOLON 58122 ISRAEL

ROBERT SHUMWAY
410 MRAK HALL
DIVISION OF STATISTICS
UNIVERSITY OF CALIFORNIA
DAVIS, CA 95616-8671

DAVID SIMPSON
IRIS
1616 N. FORT MEYER DRIVE
SUITE 1050
ARLINGTON, VA 22209

BRIAN SULLIVAN
BOSTON COLLEGE
INSITUTE FOR SPACE RESEARCH
140 COMMONWEALTH AVENUE
CHESTNUT HILL, MA 02167

NAFI TOKSOZ
EARTH RESOURCES LABORATORY, M.I.T.
42 CARLTON STREET, E34-440
CAMBRIDGE, MA 02142

GREG VAN DER VINK
IRIS
1616 N. FORT MEYER DRIVE
SUITE 1050
ARLINGTON, VA 22209

TERRY WALLACE
UNIVERSITY OF ARIZONA
DEPARTMENT OF GEOSCIENCES
BUILDING #77
TUCSON, AZ 85721

JAMES WHITCOMB
NSF
NSF/ISC OPERATIONS/EAR-785
4201 WILSON BLVD., ROOM785
ARLINGTON, VA 22230

JIAKANG XIE
COLUMBIA UNIVERSITY
LAMONT DOHERTY EARTH OBSERVATORY
ROUTE 9W
PALISADES, NY 10964

OFFICE OF THE SECRETARY OF DEFENSE
DDR&E
WASHINGTON, DC 20330

TACTEC
BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OH 43201 (FINAL REPORT)

MATTHEW SIBOL
ENSCO, INC.
445 PINEDA COURT
MELBOURNE, FL 32940

JEFFRY STEVENS
MAXWELL TECHNOLOGIES
P.O. BOX 23558
SAN DIEGO, CA 92123

DAVID THOMAS
ISEE
29100 AURORA ROAD
CLEVELAND, OH 44139

LAWRENCE TURNBULL
ACIS
DCI/ACIS
WASHINGTON, DC 20505

FRANK VERNON
UNIVERSITY OF CALIFORNIA, SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY IGPP, 0225
9500 GILMAN DRIVE
LA JOLLA, CA 92093-0225

DANIEL WEILL
NSF
EAR-785
4201 WILSON BLVD., ROOM 785
ARLINGTON, VA 22230

RU SHAN WU
UNIVERSITY OF CALIFORNIA SANTA CRUZ
EARTH SCIENCES DEPT.
1156 HIGH STREET
SANTA CRUZ, CA 95064

JAMES E. ZOLLWEG
BOISE STATE UNIVERSITY
GEOSCIENCES DEPT.
1910 UNIVERSITY DRIVE
BOISE, ID 83725

DEFENSE TECHNICAL INFORMATION CENTER
8725 JOHN J. KINGMAN ROAD
FT BELVOIR, VA 22060-6218 (2 COPIES)

PHILLIPS LABORATORY
ATTN: XPG
29 RANDOLPH ROAD
HANSCOM AFB, MA 01731-3010

PHILLIPS LABORATORY
ATTN: GPE
29 RANDOLPH ROAD
HANSCOM AFB, MA 01731-3010

PHILLIPS LABORATORY
ATTN: TSML
5 WRIGHT STREET
HANSCOM AFB, MA 01731-3004

PHILLIPS LABORATORY
ATTN: PL/SUL
3550 ABERDEEN AVE SE
KIRTLAND, NM 87117-5776 (2 COPIES)